

**Geologic, Geomorphic and Chemical Characteristics
of Wetlands Selected for Use in Biocriteria
Development by the Montana Department of
Environmental Quality**

by

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for the

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Abstract

Geologic, geomorphic and hydrologic characteristics of 80 Montana wetland sites selected by the Department of Environmental Quality for the development of bioassessment protocols are assembled and summarized. Chemical data are reviewed in the context of geomorphic setting and hydrologic controls, and a provisional geoclimatic classification is qualitatively evaluated with respect to observed water chemistry. Likely mechanisms for maintaining moderate alkalinity in certain depressional wetlands are evaluated, and historical information describing hydrologic variability of the wetland sites is reviewed where available.

Introduction

The primary purposes of this component of the DEQ wetland characterization project are to develop a database of basic geologic, geomorphic and climatic information about the sampling sites used in the development of wetland bioassessment protocols, and to relate these features of the wetlands to water column and sediment chemistry. The physical setting of other wetland sites may then be used to guide expectations for wetland chemistry and chemically sensitive biological characteristics.

Characteristics of the individual sites are summarized in site data summaries as Appendix A, and in narrative site summaries attached as Appendix B. Bibliographic sources specific to particular wetland sites are abstracted by site in Appendix C. This summary section presents an overall picture of the distribution of physiochemical characteristics among the sample sites, and presents a provisional system of classification based on geomorphic characteristics, which is reflected in the chemical makeup of the wetlands. Wetland and drainage basin ArcInfo coverages linked to geomorphic, chemical and biological data through Arcview II are available through the Montana State Library Natural Resource Information System.

Hydrologic and geomorphic characteristics

The database fields of geomorphic and geologic characteristics describing the 80 wetland characterization sites are drawn from published work on the classification of lakes and wetlands (Winter, 1977; Cowardin, 1979; Brinson, 1993). The selected characteristics (Appendix A) are believed to have important influences on water and solute budgets in the wetland sites, and to help define the broad range of geoclimatic conditions affecting the different wetlands. They are not intended to represent a definitive set of physical characteristics for Montana's diverse wetlands.

Geomorphic characteristics are for the most part interpreted from 7.5 minute U.S. Geological Survey topographic maps covering the wetland sites. Field observations for this project augment the map data in many cases. Information gathered from land management agencies (the U.S. Fish and Wildlife Service in particular) regarding water management activities supplements and updates map information on water importation and water level control. Complete documentation of the sources of this and other information residing in the dBase III database of hydrogeomorphic characteristics (WETLANDS.dbf) can be found in Appendix D.

The geologic settings of the individual wetland characterization sites are given brief description in the individual narrative site summaries, and are reflected in fields for surficial and bedrock geologic units within the database. The

sources for these descriptions are the published and unpublished references cited in the Annotated Bibliography of Wetland Site Geology and Hydrology, Appendix C. Field observations for this project supplement the cited sources for some of the characterization sites.

The detail and currency of the geologic and hydrologic source material cited in Appendix C varies greatly between sites. In a few cases, detailed studies provide quantitative understanding of the mechanisms influencing site hydrogeochemistry. In many cases, intermediate-scale geologic mapping provides a reasonable qualitative picture of geologic setting. For a few of the characterization sites, reference searches revealed only very coarse-scale geologic mapping showing no more than the broad occurrence of bedrock and surficial geologic units.

Appendix A shows the basic descriptive characteristics of the wetland sites. The size of the wetlands in the sample set ranges from a fraction of an acre to approximately 8800 acres (Figure 1a). (Note that the areas given include the contiguous water bodies and so may in a few cases include large areas of deep-water aquatic environments.) Contributing drainage basin areas range from only 3 acres up to more than 7 million acres. Values at the upper end of this range represent the drainage basin areas of major streams supplying imported water to hydrologically manipulated wetlands; natural drainages for these wetlands are far smaller. Ratios of contributing drainage basin to wetland area (Figure 1b) range from less than 2 for a relatively large, groundwater-supported site (Brush Lake) to about 10,000 for a small riparian wetland with a large apparent contributing basin.

The 80 sampled wetlands range in elevation from 1935 to 8470 feet above mean sea level. As shown in Figure 2, few of the characterization sites are found at the higher end of this range; only 14 percent of the sites are above 5000 feet in elevation. The total relief shown by contributing drainage basins ranges from an estimated 5 feet to 6840 feet; the extreme high end of this range represents the relief of a diverted stream supplying most of the water to a lowland impoundment (Ninepipe Reservoir).

Fifty-two of the 80 sites have identified inlet streams. Ephemeral inlet streams probably contribute to some sites where map information and field observations did not show discrete surface inflow. Forty-eight sites have identified outlet streams, while the rest are believed to be closed with respect to surface water at the observed water levels. Geomorphic evidence indicates several of the presently "closed" wetlands have experienced water levels allowing surface water drainage during the recent geologic (and probably historic) past. Many of these are believed to have significant groundwater outflow, based on the water chemistry exhibited.

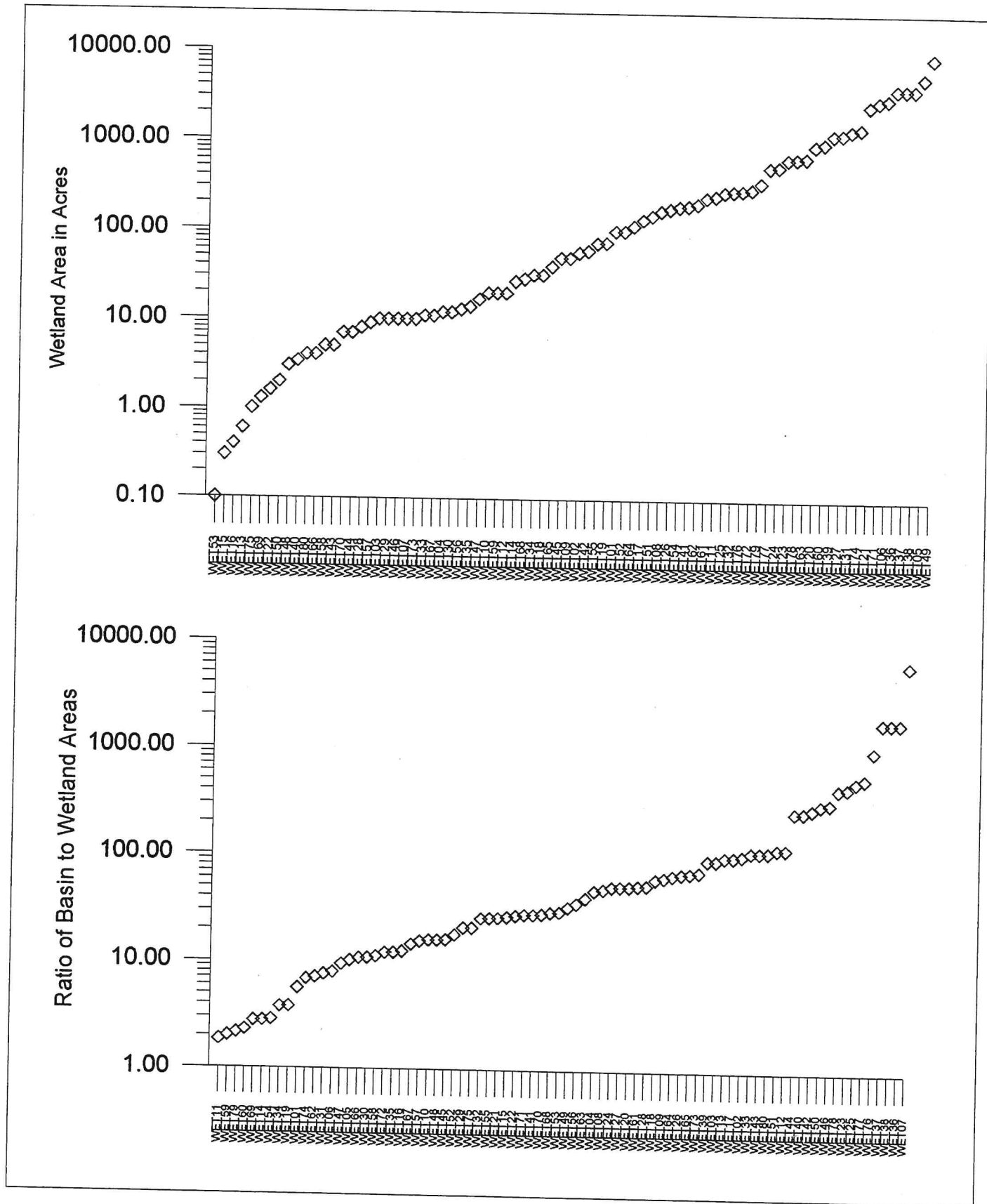


Figure 1 (a).Areas of the wetlands sampled for the DEQ wetlands characterization program.
(b) Drainage basin to wetland area ratios for the DEQ wetland characterization sites.

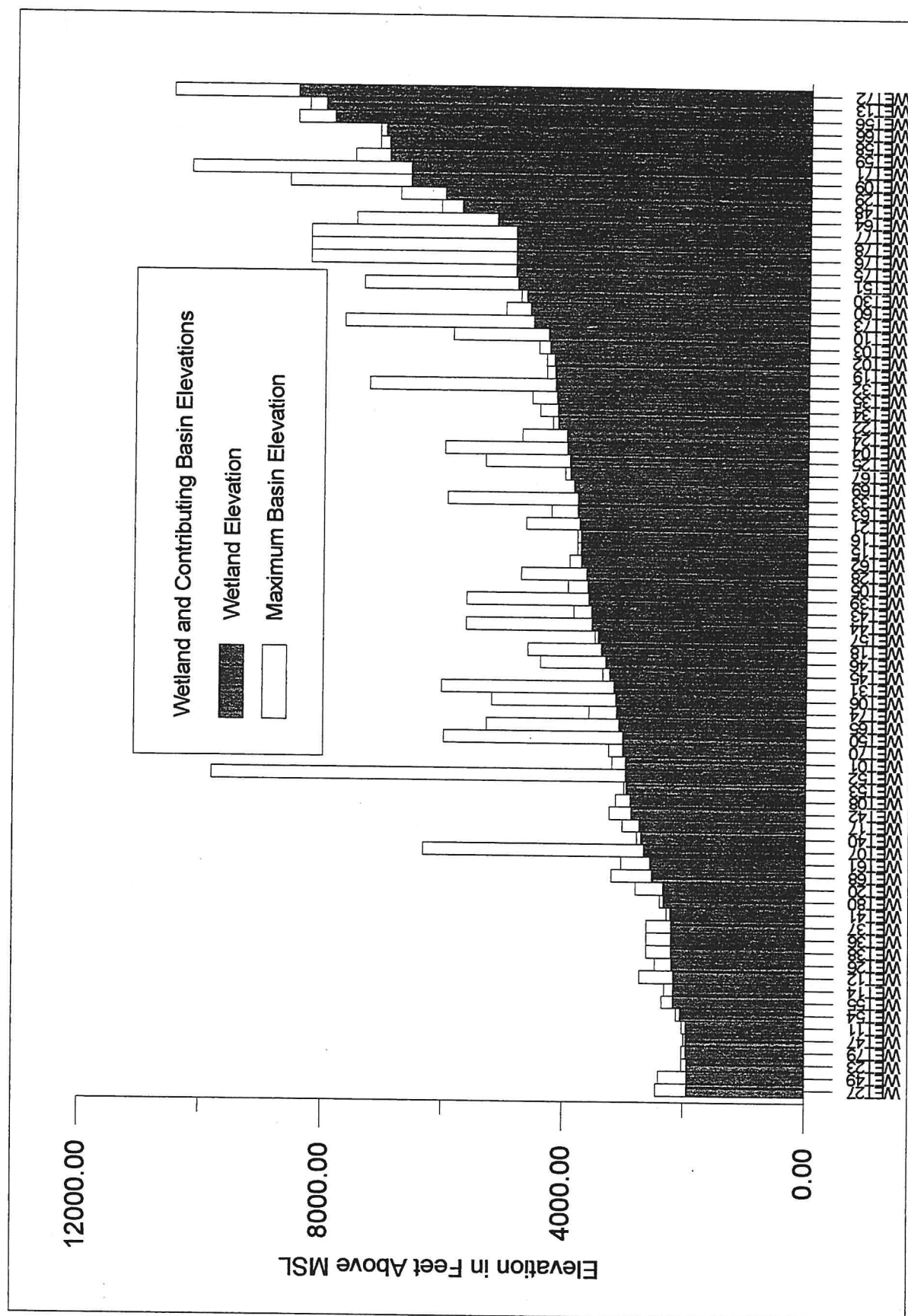


Figure 2. Elevations of the DEQ wetland characterization sites and maximum elevations of contributing drainage basins.

Twenty-eight of the 80 sites are known to be modified by impoundments, and twelve have significant known water imports from outside of their natural drainage basins.

Forty-five of the sampled wetlands are underlain by glacial materials, including till, outwash and glaciolacustrine sediments. Thirteen sites are underlain by recent alluvium, and fourteen by primarily lacustrine (or paludal) sediments of nonglacial origin. Of the remaining eight wetlands, three are underlain by sediments believed to be composed dominantly of mine tailings, one by a wide variety of Quaternary-aged deposits including volcanic rocks, and four have unknown surficial geologic characteristics.

At twenty-eight of the wetland characterization sites, surficial deposits are underlain by Cretaceous-aged sedimentary rocks, typically one of the widespread shale formations of the central and eastern Montana. At twenty-one western sites, surficial sediments rest on metamorphosed sedimentary rocks of the Proterozoic (late Precambrian) Belt Supergroup. Sandstone and shale of the early Tertiary Fort Union Formation underlies surficial deposits at fourteen of the wetlands, and mid-to-late Tertiary sediments of the western Montana valleys underlie twelve of the wetlands at depth. Bedrock geology at the remaining five sites consists of various sedimentary and igneous lithologies ranging in age from early Paleozoic to Quaternary.

The U.S. Army Corps of Engineers Wetlands Research Program has developed an approach to the hydrogeomorphic classification of wetlands. This approach is based on a primary distinction between wetland types referred to as depressional, fringe, riverine and extensive peatland (Brinson, 1993). These broad classes are intended to provide a generally applicable framework for aggregating functionally similar wetlands within geographic regions, while accommodating more specific geomorphic classification appropriate to the region.

Thirty-four of the wetland characterization sites are considered depressional in Brinson's sense, 29 are considered fringe sites, 13 are considered riverine, and 4 are considered extensive peatlands. Fringe sites include a number of lakes, closed with respect to surface water, which might also be classified as "depressional". These water bodies are large and persistent enough that lacustrine shoreline processes are believed to play an important role in the dynamics of the wetlands. In addition to the few "extensive peatlands", (including only those sites where authigenic organic accumulations derived from macroflora are thought to dominate the site's hydrology), numerous riverine and depressional sites exhibit some peat accumulation. The small list of extensive peatlands also includes one site (WET04, Bent Flat Fen) where the organic-rich, calcareous sediments may not meet all criteria for classification as peat.

Climate

It is axiomatic that climatic factors play a key role in the distribution and character of wetlands. Characterizing the physical setting of the 80 wetland sites, distributed over a wide range of climatic zones, calls for simple and available measures of precipitation and relative evaporative intensity. Interpolated mean annual climatic statistics are available on a 3' latitude by 3' longitude cell basis for Montana from the Montana Agricultural Potentials System (MAPS) Atlas (Caprio et al, 1994). MAPS values for climatic characteristics are based on relatively short periods of record (1941-1970 for mean annual precipitation) and do not provide information on seasonal or annual variability. In high-elevation areas of steep climatic gradients and sparse data, mean precipitation and evaporation values are expected to have low precision. Mean values are nevertheless believed to provide a valuable relative indication of climatic conditions at the various wetlands.

To provide some picture of climatic variability, precipitation data from the long-term (generally 30 years or more) climatic station considered most representative of each site were also recovered from the EarthInfo database. Where no direct measurements of wetland hydrologic conditions are available (almost all of the characterization sites), precipitation records provide a useful proxy record of trends prior to the time of sampling.

Figure 3 summarizes the mean annual precipitation, estimated mean annual (Penman) evaporation, and the "net precipitation" (defined simply as the difference between the precipitation and calculated evaporation values) for the 80 sites. Note that the "net precipitation" is intended as a relative scaler of the intensity of evaporative forcing among the sample sites, not as a direct measure of complex and idiosyncratic water budgets. Mean annual precipitation for the wetland sites ranges from 11 to 70 inches per year, while the theoretical Penman mean annual evaporation ranges from 26 to 43 inches per year. Only a few high-elevation sites show "net precipitation" values greater than zero.

The monthly distributions and historical records of precipitation for the selected climatic stations are shown in the individual site data summaries, Appendix A. Generally, seasonal precipitation distribution at eastern and central Montana sites is dominated by spring and summer thunderstorm activity, while western and northwestern sites receive substantial winter precipitation. Recent precipitation trends near the sampled wetlands vary widely.

Water Chemistry Common constituents

Data collected by the DEQ from the 80 wetland characterization sites includes major-ion, nutrient and trace element

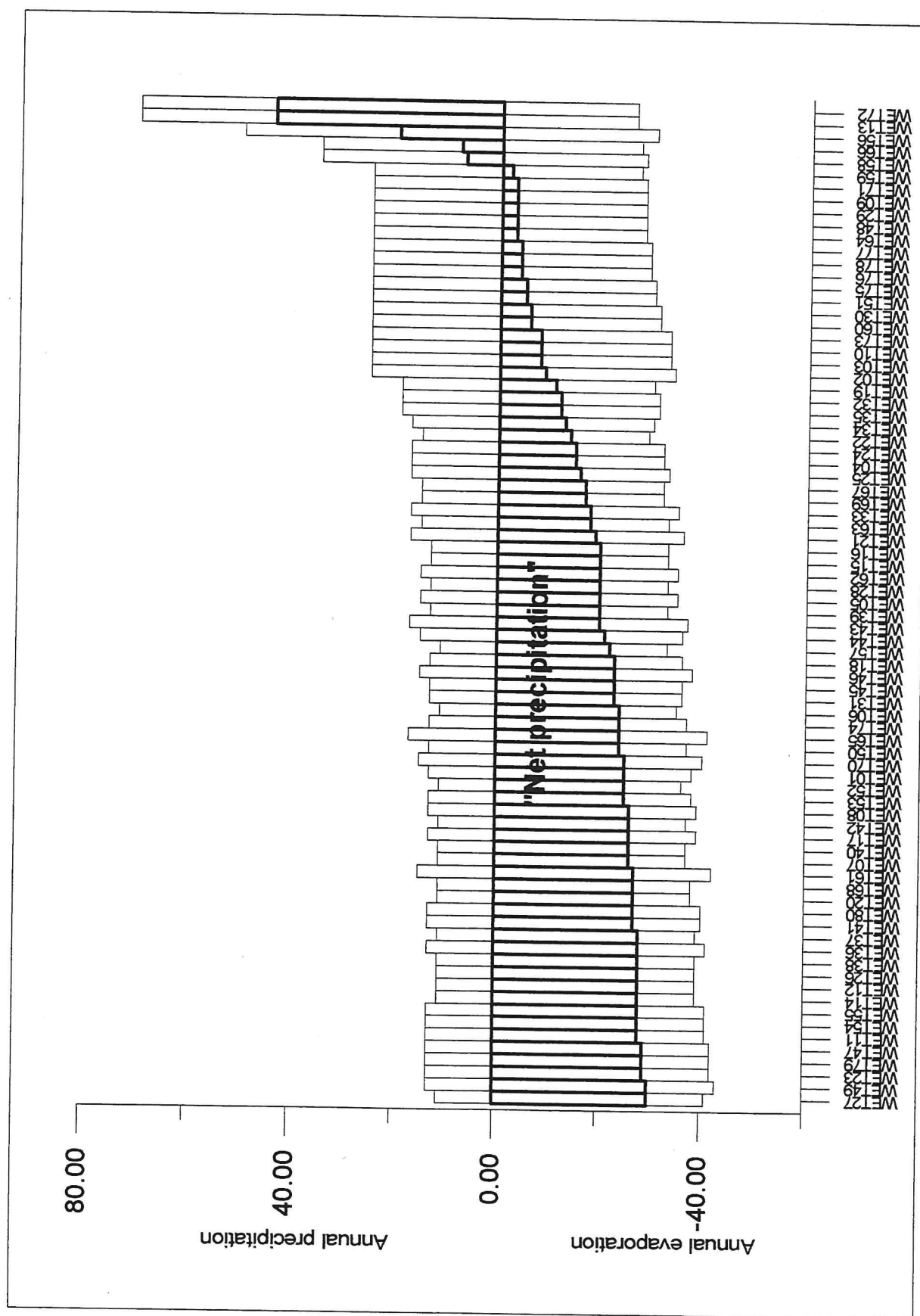


Figure 3. Mean annual precipitation and estimated annual evaporation for the DEQ wetland characterization sites.

concentrations. Nitric acid extracts of wetland sediments were also analyzed for a suite of major and trace constituents. Major anion analyses were carried out on unfiltered, refrigerated and darkened samples, and major cation analyses were conducted on unfiltered, acidified samples. Both procedures may lead to analyses which are not representative of dissolved water chemistry, particularly for turbid and/or reactive samples. Most of the more turbid samples have low to moderate charge balance errors. Several of the apparently reactive samples show higher charge balance errors possibly reflecting the loss of alkalinity to carbonate minerals prior to analysis.

Trace element analyses (including those for phosphorous) are total recoverable values, carried out on unfiltered, acidified samples; no dissolved analyses of trace constituents were included as part of this program. Field measurements of pH, specific conductance, dissolved oxygen and turbidity were collected at the time of sampling. Field alkalinity measurements were not made, and unstable alkalinities (indicated by significant pH shifts between sample collection and lab analyses) characterize some samples; several of these are from sites interpreted as influenced by chemically unequilibrated ground-water discharge to the wetlands sampled.

Figure 4 shows the wide diversity in major-ion chemistry exhibited by the wetland sample sites. Chemical compositions range from dilute calcium-bicarbonate water to hypersaline sodium sulfate brines. High-magnesium compositions are represented by many of the closed basins of intermediate salinity, and dilute calcium sulfate compositions by a few mining-impaired sites. Sodium-carbonate compositions are rare, represented only by the Schrammeck Lake sample. High-chloride water compositions (>20% milliequivalent anions) are not represented in the sample set except by one dilute site with a large analytical charge-balance error, and by one wetland believed to be influenced by deep groundwater discharge. High-chloride saline systems are not represented and probably do not represent a significant component of natural wetland chemical variability in Montana.

Figure 5 shows concentrations of individual common ions plotted against total dissolved solids concentrations. Most major solutes show a dominant increasing trend with increasing dissolved solids; calcium and total alkalinity concentrations in the sampled wetlands do not correlate closely with salinity, suggesting that divergent chemical pathways controlled at least in part by calcium carbonate solubility have a substantial influence on wetland water chemistry.

The qualitative relationships shown in Figure 5 and the chemical precipitates observed in many of the 80 wetlands raise questions of mineral equilibria within the wetland environments. Selected mineral phase saturation indices for water collected from

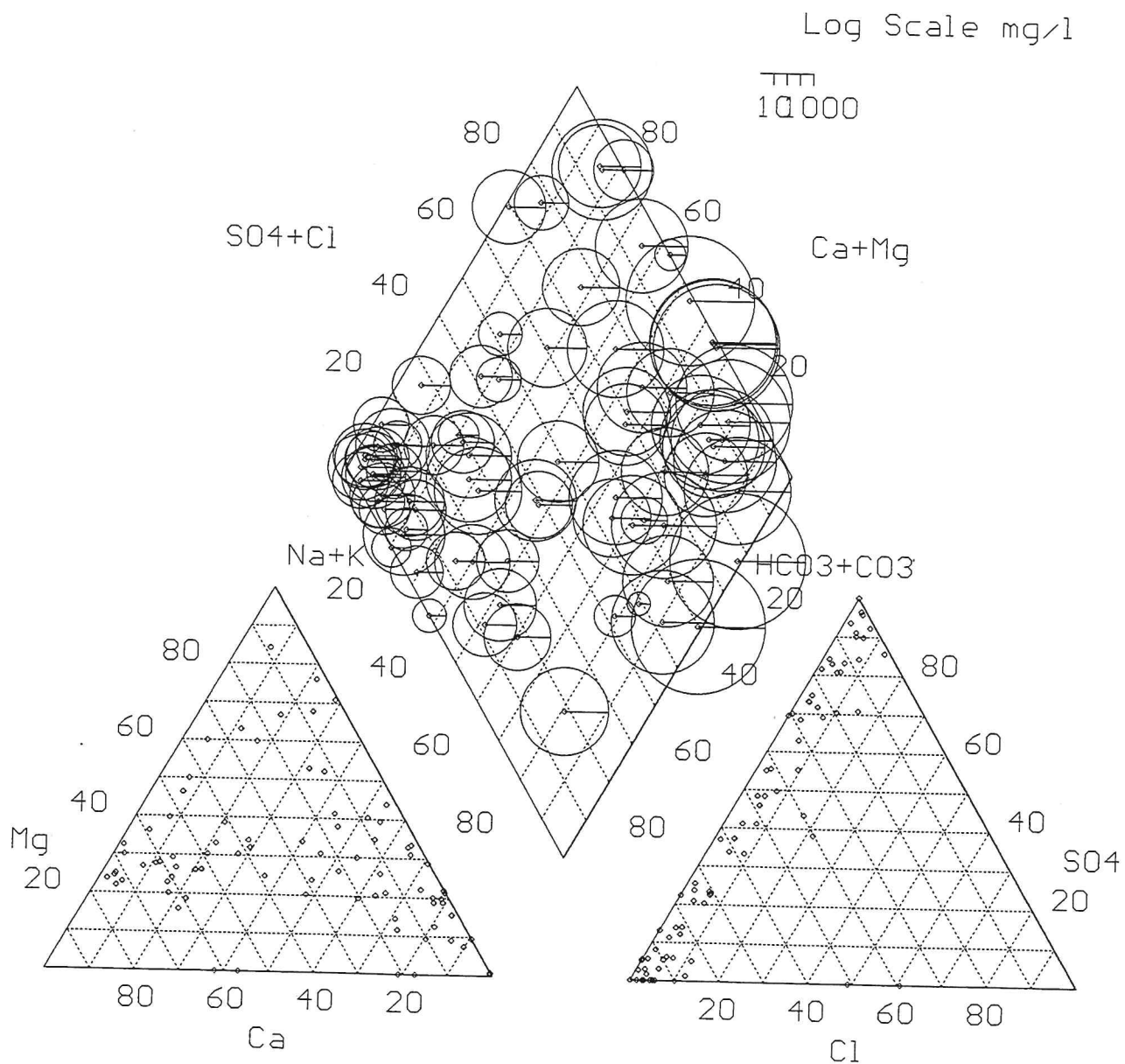


Figure 4. Piper trilinear diagram of water chemistry of the DEQ wetland characterization sites. Circles are proportional to the log of total dissolved solids concentrations.

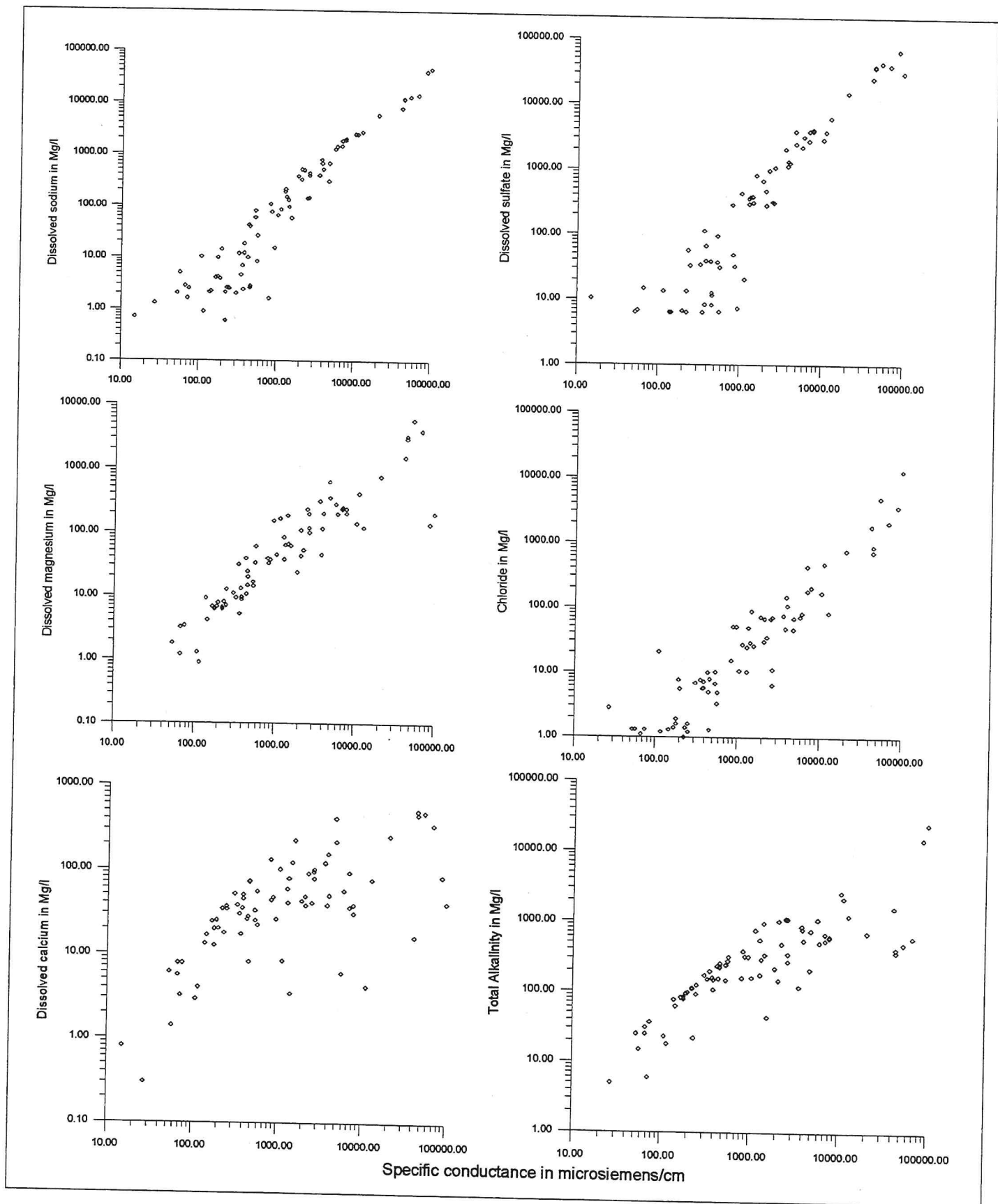


Figure 5. Relationships between major ions and specific conductance for the DEQ wetland characterization sites.

the characterization sites are shown in Table 1. Note that all samples are shown in this table; calculated saturation should be viewed with the tabulated charge balance errors in mind. Generally, most of the sampled sites are near or above theoretical equilibrium concentrations for calcite and aragonite (CaCO_3) and dolomite (Ca,MgCO_3). This is consistent with observed marl or tufa formation in a number of the wetland sites, and with high sediment concentrations of extractable calcium in sediment samples from others. Fourteen of the 80 sites sampled had (at the time of sampling) saturation indices below -1.0, indicating highly undersaturated conditions; included among these are the very dilute high-elevation sites and those with depressed pH known to be impacted by acidic mine drainage. Twenty-eight sites exhibited calcite saturation indices greater than 1, indicating a relatively high degree of supersaturation, and suggesting calcite and aragonite precipitation may be inhibited in many wetland settings.

Gypsum and mirabilite saturation indices indicate only a few sites reached or approached equilibrium with sulfate minerals at the time of sampling. These include the hypersaline Hailstone Reservoir, Kingsbury Lake, Big Lake and Oilmont sites (saturated with respect to gypsum, CaSO_4) where active sulfate(?) precipitation was observed, and hypersaline North Goose and White Lakes, near saturation with respect to mirabilite ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$). Other samples approaching theoretical equilibrium with gypsum include those from a few moderately saline, high-calcium sites such as the Jarina WPA and Benton Lake, and Warm Springs Pond #1, an impacted site where high-sulfate water has been treated with lime for pH and metals control.

Trace constituents

Figures 6 through 15 show the distribution of total recoverable (water column) concentrations for 6 trace elements across the 80 wetland sites. Patterns of elevation attributable both to natural geochemical processes and to anthropogenic input can be seen in many of the selected parameters. Since the trace element analyses represent unfiltered and sometimes turbid samples, only limited interpretations are possible; trace constituents reported for these samples may occur in dissolved forms, as "recoverable" solids, or both.

Arsenic concentrations show an apparent correlation with total dissolved solids concentrations, with mining-impacted sites high in proportion to their dissolved solids and the highest absolute concentrations shown by saline sites in northeastern Montana and the Ovando Valley. Most sites across all geologic and geomorphic settings contained detectable concentrations of water-column arsenic.

Water-column boron concentrations were below detection limits in most western Montana wetlands. The exceptions are either in

Site	CBE	Turb	calc	arag	magnes	dolo	gyp	mirab	Site	CBE	turb	calc	arag	magnes	dolo	gypsum	mirab
WET01	21.60	0	0.8210	0.6700	2.530	3.6890	-2.8120	-5.810	WET41	0.99	0	0.9680	0.8190	0.594	1.9090	-1.9130	-7.005
WET02	20.90	0	1.2970	1.1500	1.143	2.8000	-3.4480	-11.140	WET42	0.23	5	0.7920	0.6410	0.780	1.9100	-0.8100	-4.485
WET03	7.80	0	-2.256	-2.399	-2.510	-4.391	*****	*****	WET43	1.22	0	1.3930	1.2440	1.120	2.8610	-0.9020	-4.442
WET04	12.80	0	-0.480	-2.010	-0.884	-6.040	-2.5800	-10.570	WET44	2.68	50	0.0660	-0.850	-0.735	-3.330	*****	*****
WET05	2.10	10	1.1830	1.0360	1.580	3.1220	-0.6570	-0.657	WET45	7.03	0	0.9660	0.8220	0.675	2.0090	*****	*****
WET06	4.07	5	1.5130	1.3590	2.551	4.3820	0.0980	-0.552	WET46	0.07	5	1.5340	1.3880	1.743	3.6370	-0.4270	-4.154
WET07	4.06	6	0.5240	0.3710	0.145	0.9970	-2.3820	-6.914	WET47	24.09	10	0.3470	0.1970	0.623	1.3140	-1.3400	-5.005
WET08	6.34	0	0.1510	0.0080	0.618	1.1400	-3.3390	-8.555	WET48	-9.99	0	-6.572	-6.718	5.940	*****	*****	*****
WET09	11.73	7	-4.087	-4.236	*****	*****	*****	*****	WET49	7.13	0	0.8940	0.7450	-0.787	2.2060	-1.4920	-5.477
WET10	10.00	0	-1.360	-2.930	-0.581	-4.190	-2.8010	-9.376	WET50	1.22	5	-3.572	-3.712	-3.894	-7.086	*****	*****
WET11	2.27	0	0.7970	0.6480	2.478	3.6240	-2.0990	-3.476	WET51	0.42	20	0.0410	-1.100	-0.685	0.3050	-2.1850	*****
WET12	4.86	10	1.3680	1.2230	1.525	3.2600	-1.3850	-5.913	WET52	7.58	10	-0.3460	-0.4890	-0.863	-8370	*****	*****
WET13	2.71	0	-1.682	-1.833	-2.396	-3.737	-3.1440	-10.817	WET53	9.44	5	1.4900	1.3470	2.316	4.1800	-3.4170	-9.920
WET14	5.29	5	1.6290	1.4820	1.507	3.4920	-1.2200	-5.893	WET54	11.17	350	1.3810	1.2290	2.998	4.7080	-2.2650	0.014
WET15	0.56	0	-3.698	-3.850	-4.382	-7.752	-3.5010	-10.686	WET55	6.79	0	1.3510	1.2040	1.560	3.2660	-0.7540	-2.627
WET16	8.09	0	-3.494	-3.649	-4.043	-7.225	*****	*****	WET56	5.16	15	-5.648	-5.802	*****	*****	-4.0750	-9.782
WET17	5.46	0	0.7670	0.6140	0.199	1.2890	-2.2890	-7.352	WET57	1.38	80	1.7270	1.5870	2.911	5.0180	0.1690	-1.558
WET18	0.89	0	1.0910	0.9490	1.136	2.6030	-3.1120	-10.871	WET58	11.21	0	*****	*****	*****	*****	-4.1300	-11.347
WET19	4.12	35	0.8050	0.6600	2.923	4.0950	-2.4190	-3.239	WET59	14.56	0	*****	*****	*****	*****	-1.9920	-8.524
WET20	6.67	30	1.3790	1.2320	1.466	3.2030	-0.9410	-4.661	WET60	9.30	0	0.7440	0.5950	0.082	1.1740	-2.4600	-10.592
WET21	3.93	20	0.2330	0.0850	0.807	1.3960	-1.1320	-4.467	WET61	9.17	90	0.1670	0.0120	-0.141	0.3390	-2.0990	-6.459
WET22	3.13	0	0.7870	0.6430	0.341	1.4970	-2.8540	-11.119	WET62	19.74	90	1.4990	1.3560	1.602	3.4740	-1.7670	-5.301
WET23	1.15	25	-6.850	-8.380	2.480	2.1200	-4.0430	-2.593	WET63	3.39	17	1.4660	1.3090	1.744	3.5130	-0.7320	-2.796
WET24	2.23	50	1.5780	1.4270	2.361	4.2760	0.2700	-0.885	WET64	2.29	10	-2.434	-2.582	-2.843	-4.922	-2.2390	-9.941
WET25	2.31	50	1.5970	1.4450	2.050	3.9820	-0.1260	-1.597	WET65	3.04	0	-0.0910	-0.2430	-0.939	-6.950	-2.5870	-11.615
WET26	2.36	1000	0.7670	0.6160	0.425	1.5270	-1.2410	-4.567	WET66	14.60	0	-4.197	-4.350	-4.998	-8.868	-3.3560	-11.044
WET27	2.57	60	1.5930	1.4400	1.594	3.5110	-1.3270	-3.711	WET67	4.03	50	0.9460	0.7910	0.516	1.7740	-1.0420	-5.880
WET28	5.55	0	-1.588	-1.738	-2.507	-3.752	-3.0700	-10.217	WET68	9.69	5	0.1380	-0.040	0.312	0.8240	*****	*****
WET29	13.57	10	-1.404	-1.554	-2.071	-3.133	*****	*****	WET69	16.52	10	0.2260	0.0800	0.089	0.6790	-2.2770	-7.584
WET30	0.17	0	0.5930	0.4460	0.761	1.7100	-0.0610	-4.678	WET70	18.81	30	1.3660	1.2230	2.812	4.5520	-3.7740	-7.958
WET31	0.35	0	1.5340	1.3870	2.431	4.3220	0.1960	-1.170	WET71	10.28	20	0.4650	0.3130	-0.096	0.7030	*****	*****
WET32	3.43	20	1.5380	1.3940	2.013	3.9190	-2.7630	-8.543	WET72	0.92	0	-2.410	-3.960	-1.163	-1.088	-2.8920	-10.644
WET33	2.45	70	-9.790	-1.130	1.656	-2.293	*****	*****	WET73	6.57	0	0.6440	0.4980	0.076	1.0800	-1.0110	-9.982
WET34	2.80	10	0.9910	0.8390	3.038	4.3630	-1.3970	-1.277	WET74	0.94	0	0.1930	0.0450	-0.222	0.3230	-0.9820	-6.481
WET35	1.74	10	1.5280	1.3830	1.852	3.7480	-1.3790	-6.360	WET75	2.87	0	0.3140	0.1610	-0.555	0.0820	-2.1830	-9.824
WET36	1.02	7	1.5430	1.3910	2.045	3.9190	-0.9620	-3.024	WET76	1.21	0	1.0010	0.8530	0.392	1.7430	-0.5100	-6.355
WET37	2.67	0	0.9690	0.8240	1.815	3.1490	-1.2150	-3.160	WET77	1.32	0	0.2730	0.1210	0.564	0.0420	-1.8480	-8.347
WET38	0.00	0	0.9690	0.8240	0.000	3.1490	-1.2150	0.000	WET78	8.89	0	-0.0580	-0.2110	-0.921	-6.490	-2.0370	-8.179
WET39	0.25	50	1.2400	1.0870	1.975	3.5430	-1.0800	-2.701	WET79	2.55	500	1.5880	1.4460	2.776	4.7380	-1.5400	-0.425
WET40	2.14	180	1.4520	1.3040	2.184	3.9910	-1.7430	-6.135	WET80	8.34	12	0.7470	0.5950	0.534	1.6120	-0.6250	-3.927
WET40	4.28	0	1.3020	1.1520	0.816	2.4590	-3.2000	-9.219									

Table 1. Charge balance errors, turbidity, and carbonate and sulfate saturation indices for the DEQ wetland characterization sites.

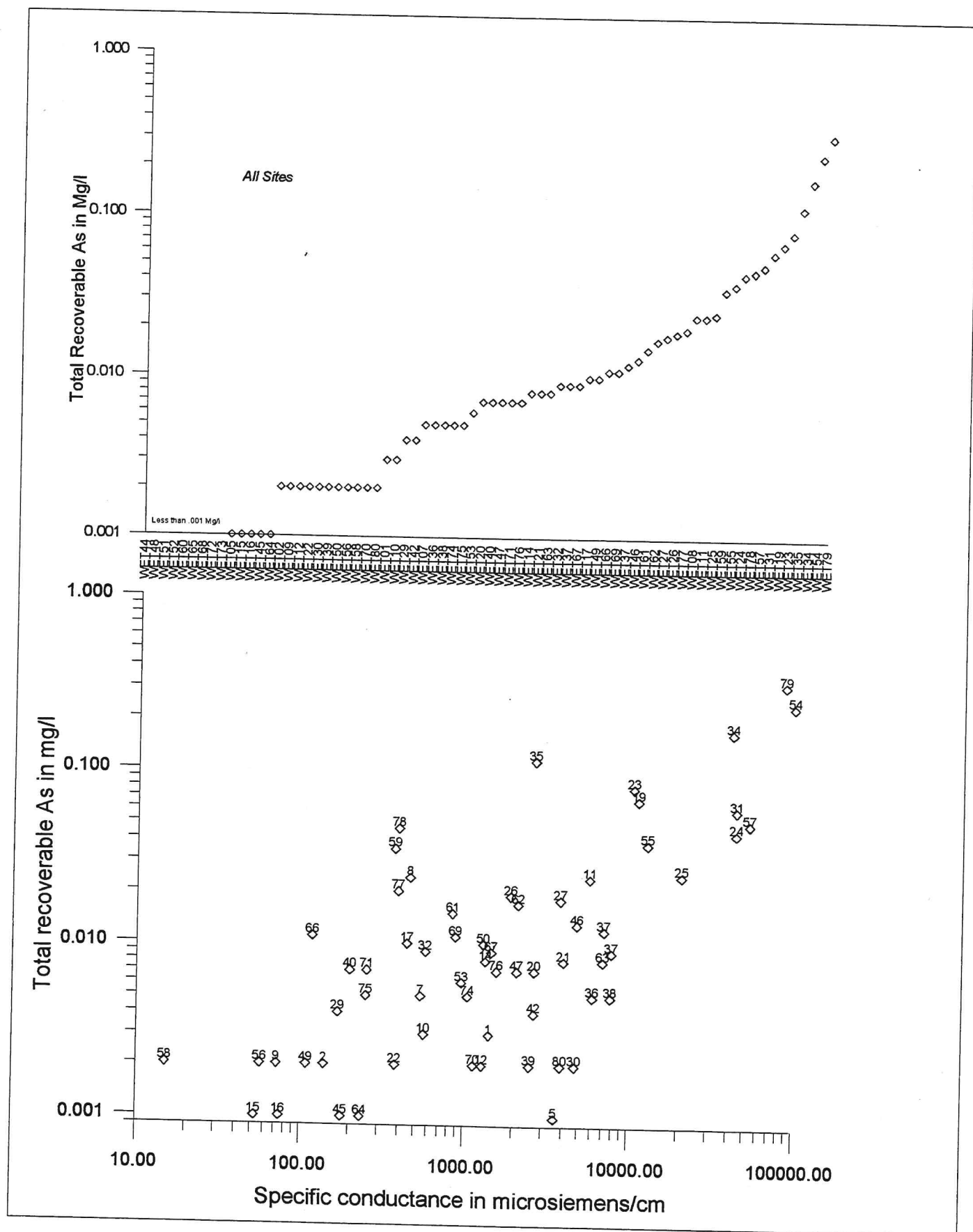


Figure 6. Distribution of recoverable arsenic and relationship to specific conductance.

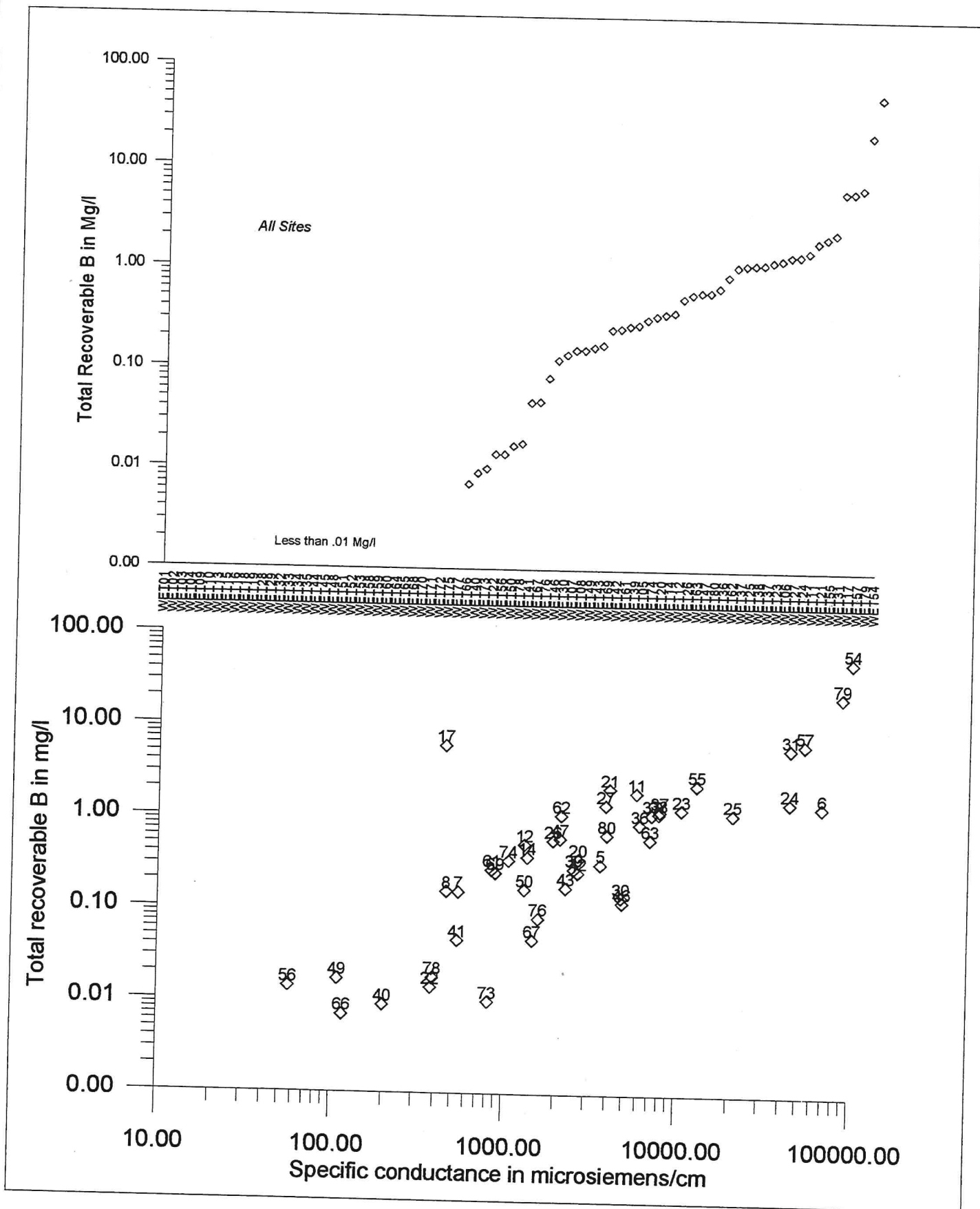


Figure 7. Total recoverable boron and relationship to specific conductance.

known mineralized areas (WET56 and WET66), are impacted by human activities (WET76, WET78 and WET69), are underlain by the western margins of the Cretaceous-aged sediments of central and eastern Montana (WET30 and WET62), or are believed to receive discharge from relatively deep ground-water flow systems (WET50 and WET73). Within the set of samples containing detectable boron, there is a strong correlation with salinity. Highly saline sites of the Lake Basin area (south-central Montana) appear to have lower boron concentrations (as a function of salinity) than north-central and northeastern sample sites.

Water-column concentrations of selenium (not shown) were below the 1 microgram/liter detection limit at all but five of the 80 wetland sites. These sites appear to share few geologic or hydrologic characteristics, occurring in riverine and closed-basin depressional settings in western and north-central Montana. Two hydrologically very different sites in the Ovando Valley (Indian Meadows and Kleinschmidt Lake) are among the 5 sites with reported selenium concentrations.

Water-column concentrations of copper, lead and zinc (where above detection limits) do not appear to show increasing relationships to salinity. Wetlands subject to mining impacts or located in mineralized areas show obviously elevated values relative to the total sample set; some notably turbid samples show elevated concentrations as well, suggesting that suspended solids may contribute metals in these cases.

In the case of lead and zinc (Figures 8 through 11), concentrations above about 10 micrograms/liter in mining-impacted sample wetlands exceed values from all other sites by 1-2 orders of magnitude. Lead and zinc concentrations at most saline, highly alkaline wetland sites (specific conductance greater than 10,000 microsiemens/cm) are below detection limits (1 microgram/liter). Detectable copper concentrations (Figures 12 and 13) are more widespread in the wetland sites; a number of wetlands in the central and south-central Montana plains exhibited copper concentrations in the 20-200 microgram/liter range, equaling or exceeding those from mine-impacted and mineralized wetlands in western Montana. Alkaline wetlands with specific conductance above 10,000 microsiemens/cm often have detectable copper concentrations up to several tens of micrograms/liter.

Most water-column chromium concentrations (not shown) in the 80 wetland sites were below detection limits. A striking pattern of elevated chromium concentration occurs, however, among the lacustrine wetland sample sites of the unglaciated central and south-central plains. Concentrations between 10 and 100 micrograms per liter (1-2 orders of magnitude above the reporting limit) occurred in five central and southern plains sites characterized by a wide range of salinity and alkalinity. Their common features include a lacustrine fringe or depressional setting and underlying

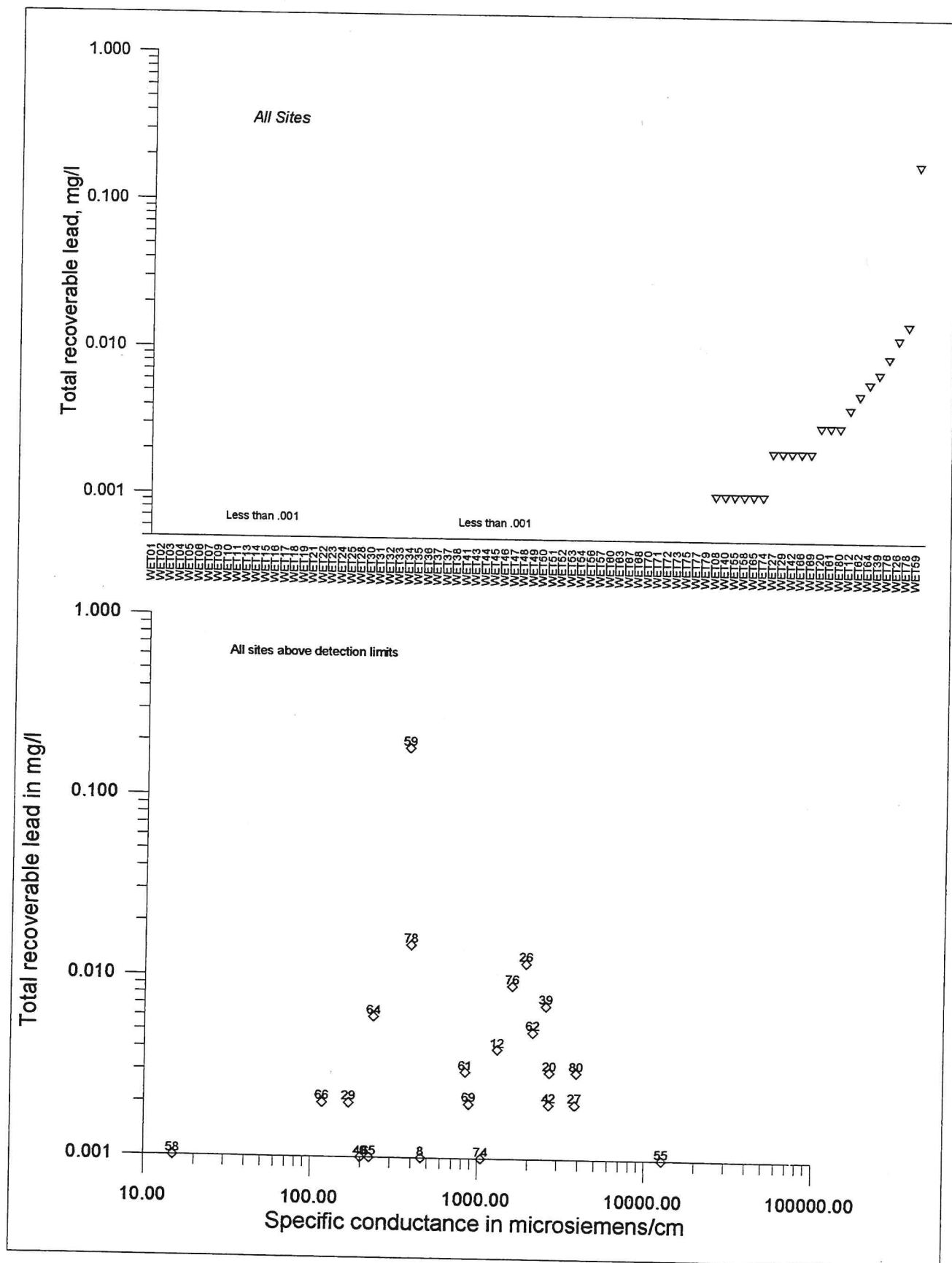


Figure 8. Distribution of total recoverable lead and concentrations plotted against specific conductance.

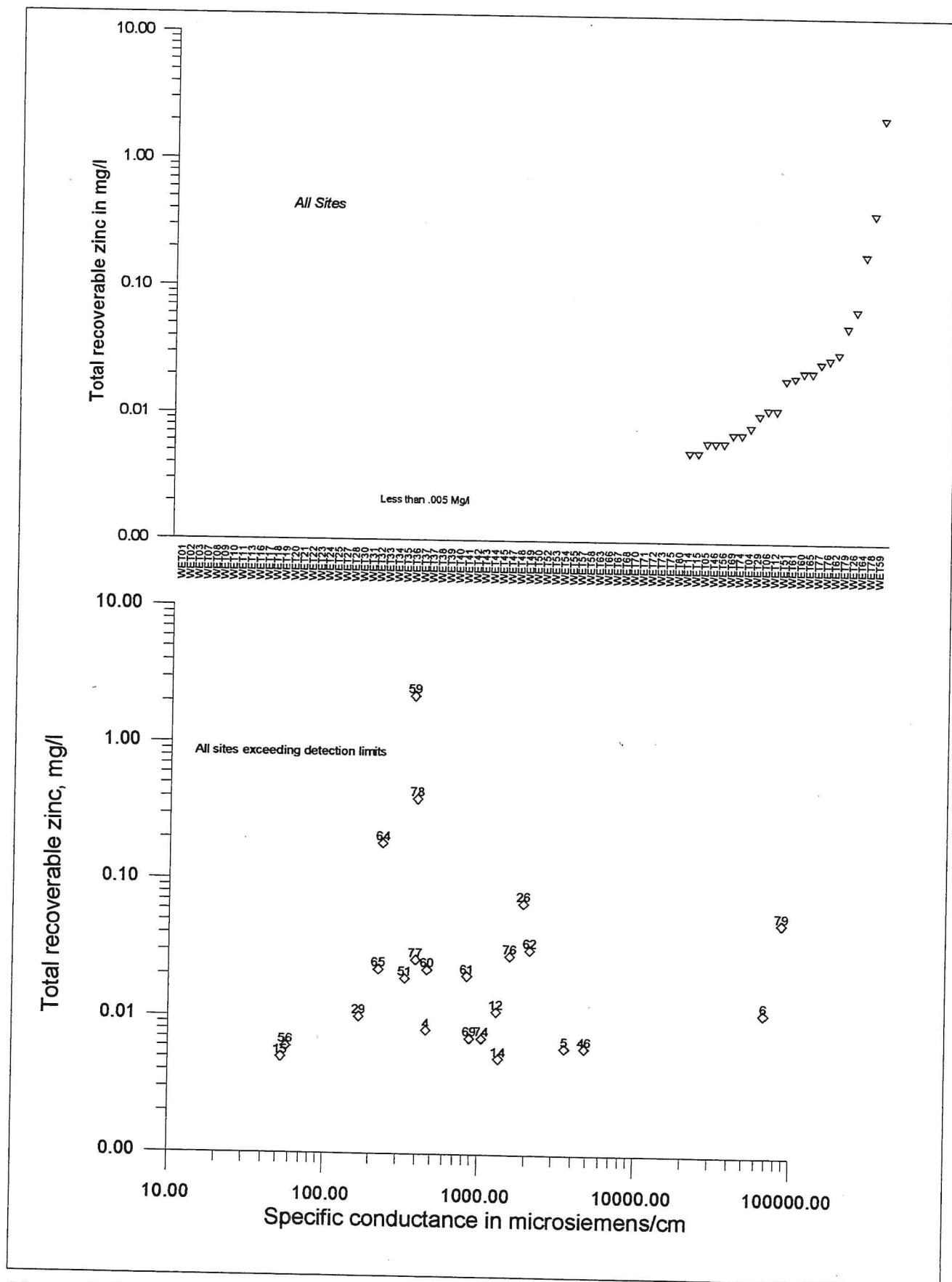


Figure 9. Distribution of recoverable zinc and concentrations plotted against specific conductance.

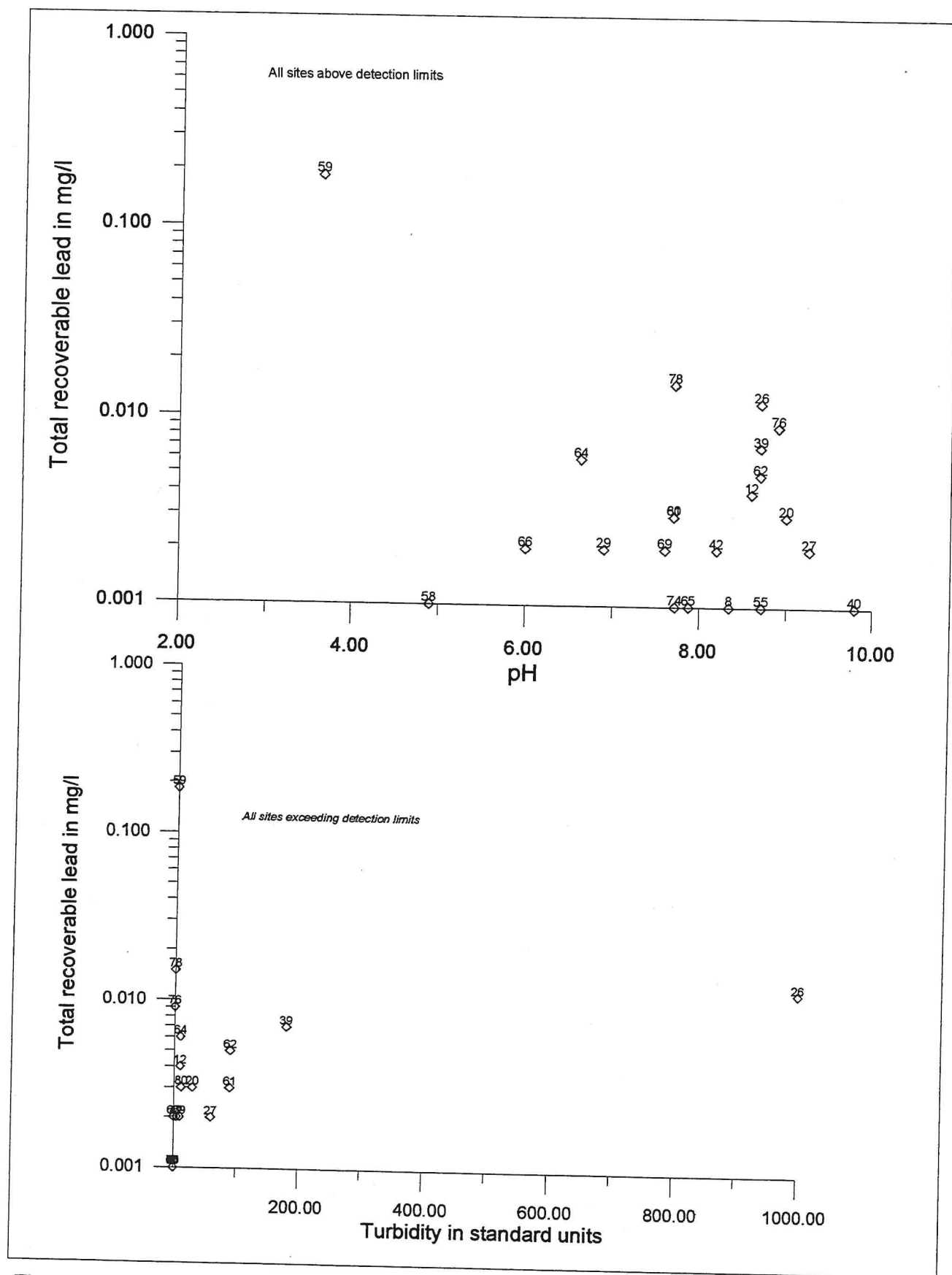


Figure 10. Total recoverable lead plotted against pH and turbidity.

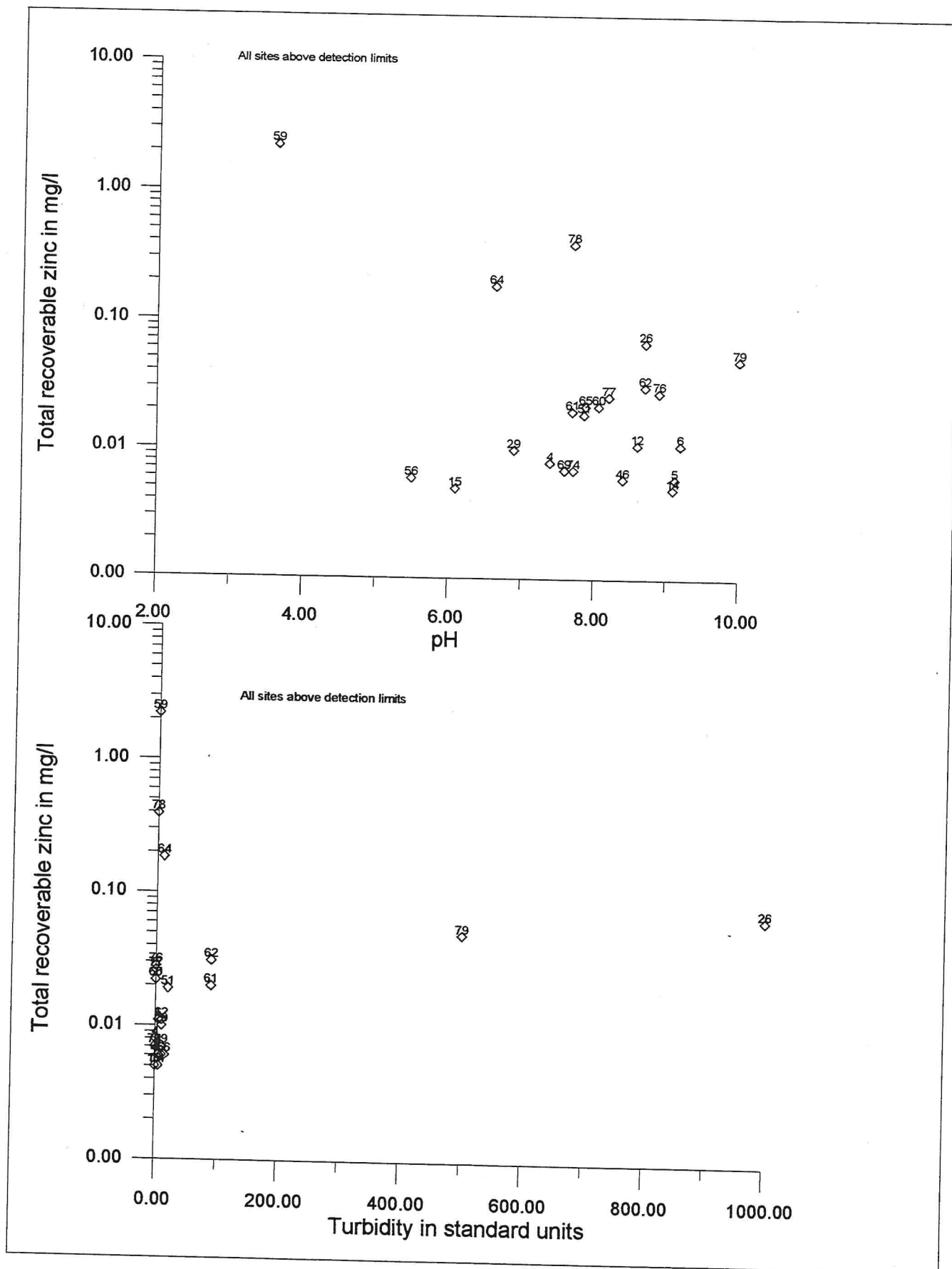


Figure 11. Total recoverable zinc concentrations plotted against pH and turbidity.

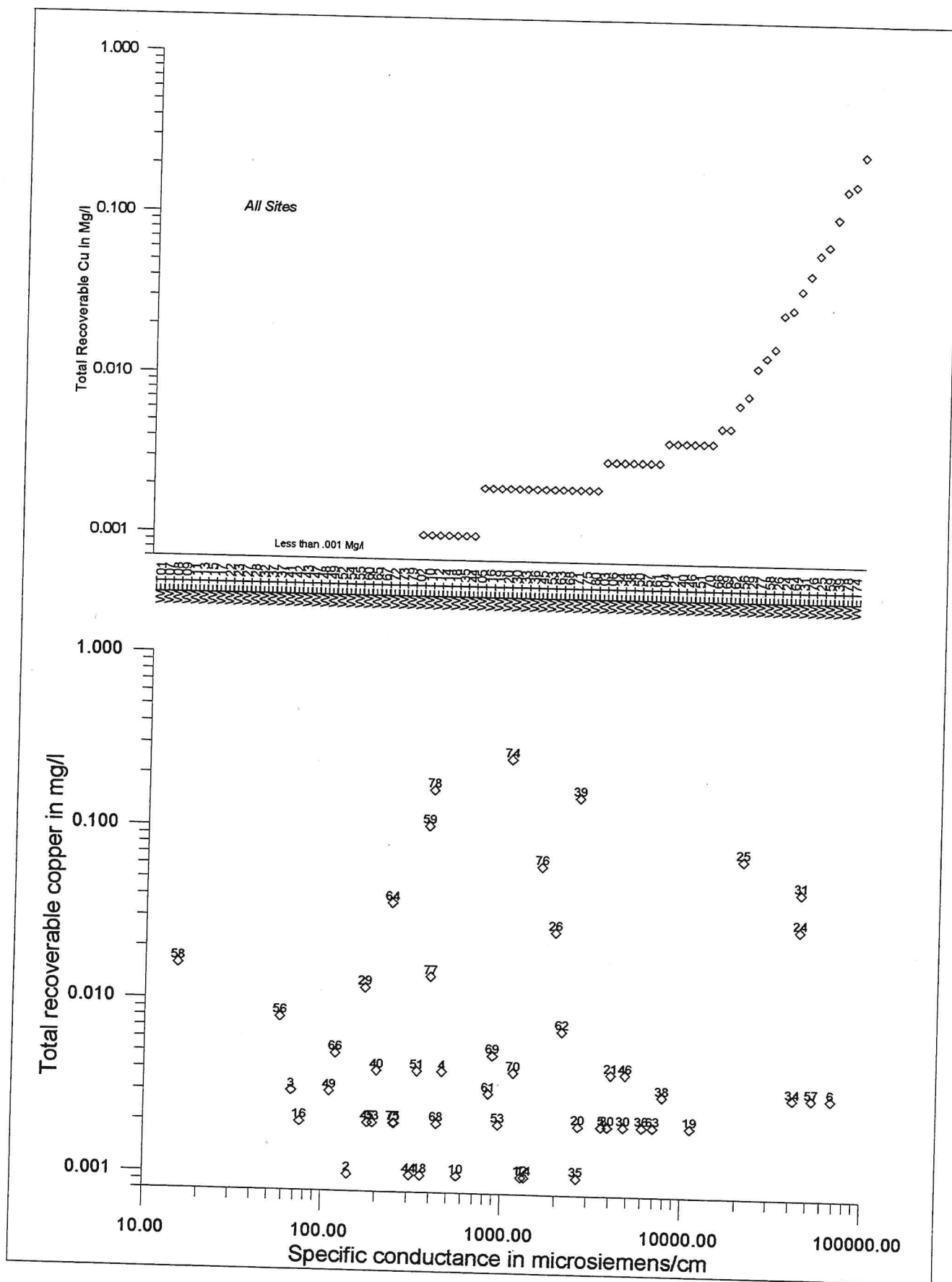


Figure 12. Distribution of recoverable copper concentrations and relationship to specific conductance.

Cretaceous-aged shale or marine sandstone. Of three other wetlands showing chromium concentrations between 4 and 10 micrograms per liter, two are also underlain by Cretaceous shales with overlying glacial materials thin or absent; the third (North Goose Lake) receives ground-water inflow from a glacial aquifer thought to be locally contaminated by oilfield production brine and drilling fluids. The very few nickel concentrations exceeding detection limits are also suggestive of regional geologic sources, but are not so obviously associated with unglaciated sites.

Total recoverable iron concentrations range from less than 10 micrograms per liter to more than 10 milligrams per liter with little apparent correlation with pH, salinity or turbidity. High total recoverable iron concentrations were found in mildly acidic impaired sites, in some naturally alkaline and saline sites of low turbidity, and in some wetlands showing high turbidity at the time of sampling. In the analyses from turbid samples, the iron reported may be largely associated with particulate matter. Several high-iron analyses also exhibit very high TOC, suggesting that organically complexed forms may be important in some sites (Hem, 1985). The proportions of solid and aqueous forms contributing to the total recoverable metal concentrations are unknown without more specific analyses.

Sediments

Qualitative observations of the 80 wetland sites indicate wide variability in the nature of their sediments, as would be anticipated based on the diverse hydrologic, geologic and water quality characteristics shown. The sampled wetlands include sediment regimes dominated by fluvial or littoral transport of allogenic material; systems characterized by chemical precipitation of authigenic minerals; and systems dominated by accumulations of organic material.

Chemically precipitated wetland sediments include: 1.) carbonate marl and marly peat in both fens and groundwater-influenced lacustrine settings (including the Chara mediated(?) marly peat of Bent Flat Fen); 2.) consolidated carbonates including tufa/travertine deposits at Bent Flat and (reportedly) at Wagner Basin, and lacustrine limestone in Brush Lake, and 3.) zoned carbonate and sulfate evaporites in saline playa wetlands.

Organic-dominated systems include peatlands, and wetlands with accumulations of gyttja-like sediments. Bentonitic clays and/or gyttja render several of the alkaline depressional wetlands nearly inaccessible to shore-based sampling.

Sediment samples collected for this study were limited to a single near-shore grab sample collected in shallow water near each biological sampling point. No grain-size or mineralogical analyses were conducted, nor was the organic content of sediment analyzed.

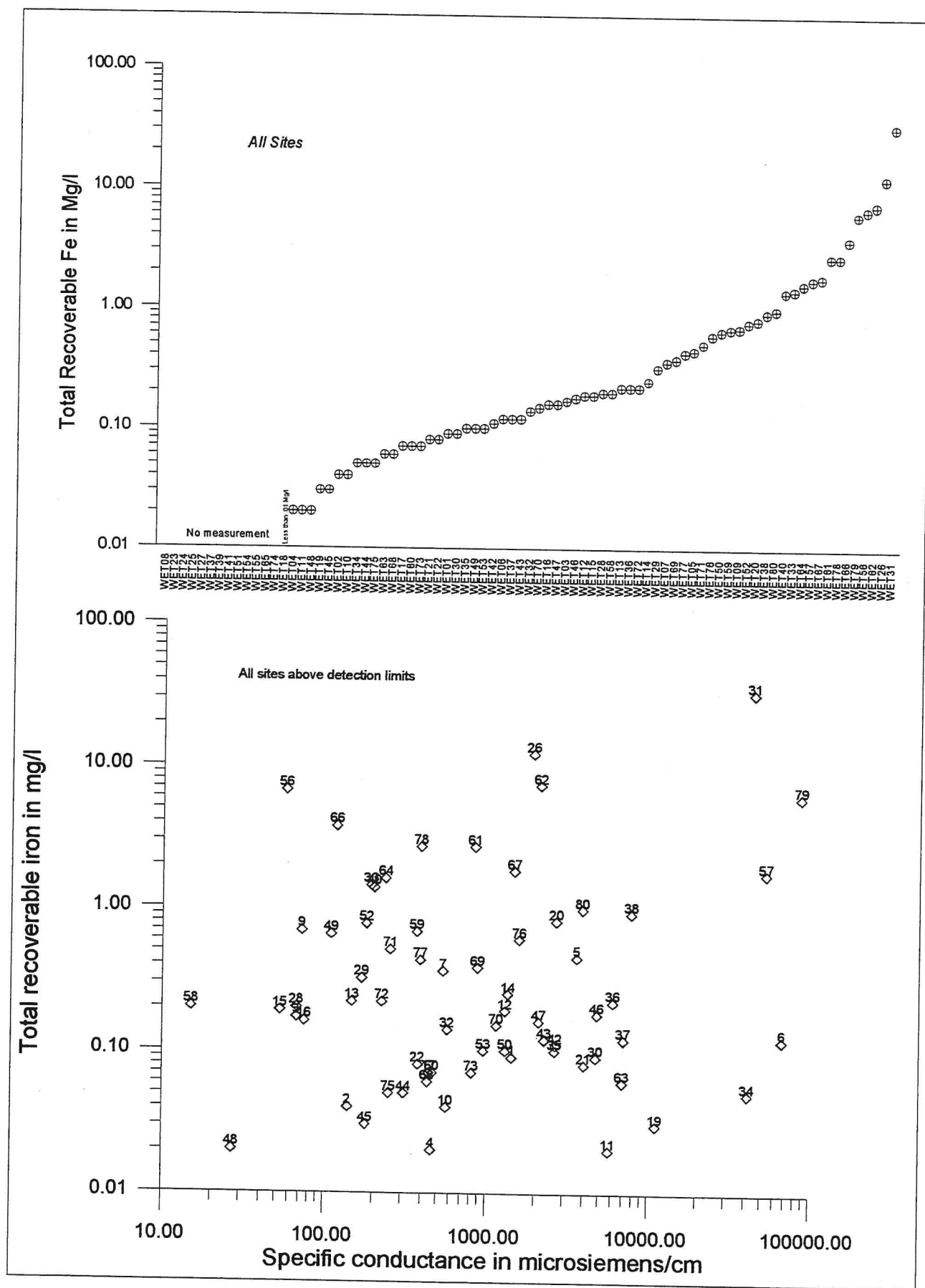


Figure 14. Distribution of recoverable iron and relation to specific conductance.

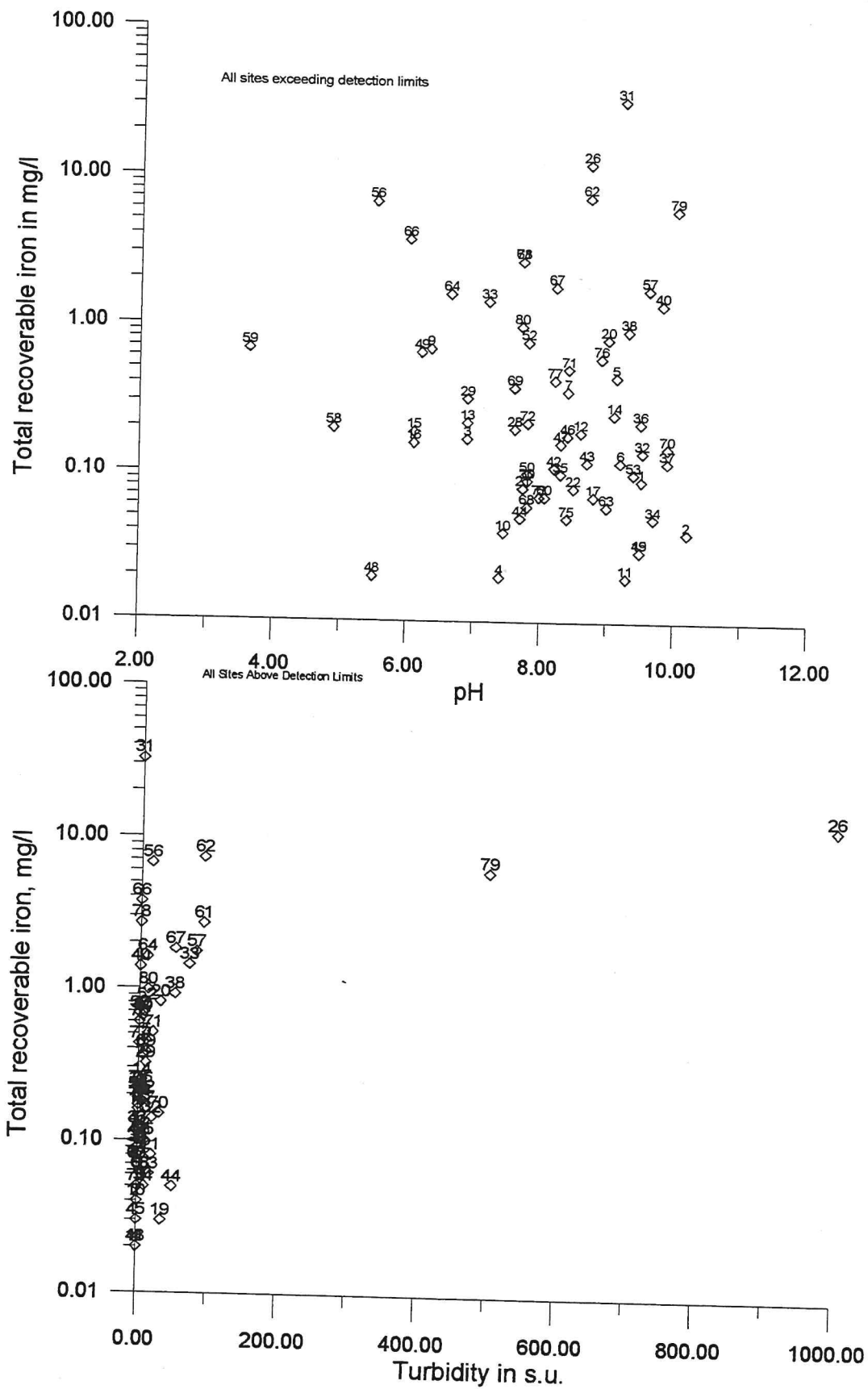


Figure 15. Recoverable iron plotted against pH and turbidity.

The objective of this sampling was limited to identifying general patterns in the concentration of extractable forms of the selected elements. No regional compilations of elemental concentrations specific to wetland sediments are known, hence comparative reference is made to the conclusions of Shacklette and Boerngen (1984), which are based on analyses of non-wetland soils and geologic materials across the U.S.. The natural distribution of elemental abundance in wetland settings probably differs from that of the surficial sediments sampled by Shacklette and Boerngen. Furthermore, sample collection and analytical methodologies differ from those employed in the DHES study; the DHES extraction method is intended to approximate the biologically available fraction of the elements analyzed, while the method used by Shacklette and Boerngen is a more aggressive extraction. Comparisons are intended strictly as a convenient benchmark.

Extractable calcium and magnesium concentrations vary over about three and two orders of magnitude, respectively, and appear to broadly reflect the carbonate saturation state of wetland waters. Wetlands characterized by water which is below theoretical saturation with respect to calcite all showed extractable calcium concentrations in sediment grab samples of less than 2000 ppm (2%), with most below 1% (Figure 16). In sites where the water column is at or above equilibrium, extractable calcium concentrations range from low values (comparable to those for the undersaturated wetlands), up to 30% by weight. A generally similar relationship appears to exist between theoretical magnesite saturation and magnesium concentration in sediment. High sediment-calcium sites include those wetlands observed to be depositing authigenic carbonate and sulfate minerals. Marl (or travertine or tufa) deposition may lend distinct and biologically important characteristics to the wetland substrate, and may also influence the partitioning of trace constituents between the water column and sediments.

Extractable arsenic concentrations from the 80 wetland sites (Figure 17) were generally below about 30 ppm, with the exception of sites directly impacted by mine drainage or mine waste deposition; four such sites exhibited concentrations in the range of 150 to 6000 ppm. Highly alkaline and hypersaline White Lake exhibited notably high extractable sediment concentrations of arsenic in comparison to the other eastern Montana wetlands sampled. 33 of the 80 samples exceed the geometric mean concentration for soils in the western U.S., and 16 exceeded the western U.S. mean by more than one geometric deviation.

Extractable boron concentrations (Figure 17) reflect regional geologic setting, and cultural impacts to the sampled wetlands. In western Montana sites, concentrations were generally below 30 ppm in unimpaired wetlands, including naturally saline sites. Extractable boron concentrations in excess of 30 ppm (up to an extreme of more than 1000 ppm at the Swamp Gulch site) occur in

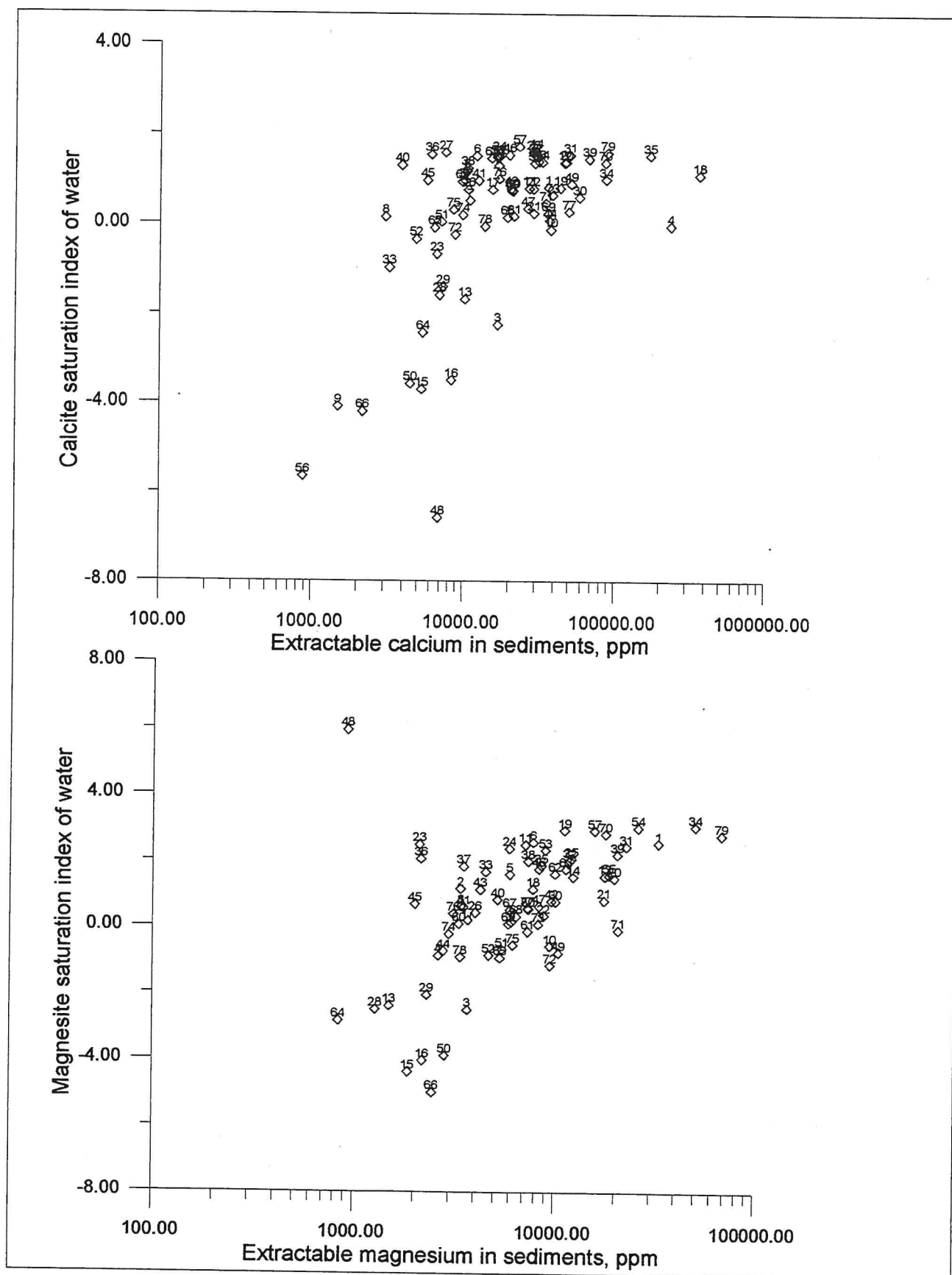


Figure 16. Extractable calcium and magnesium concentrations in sediments plotted against calcite and magnesite saturation indices.

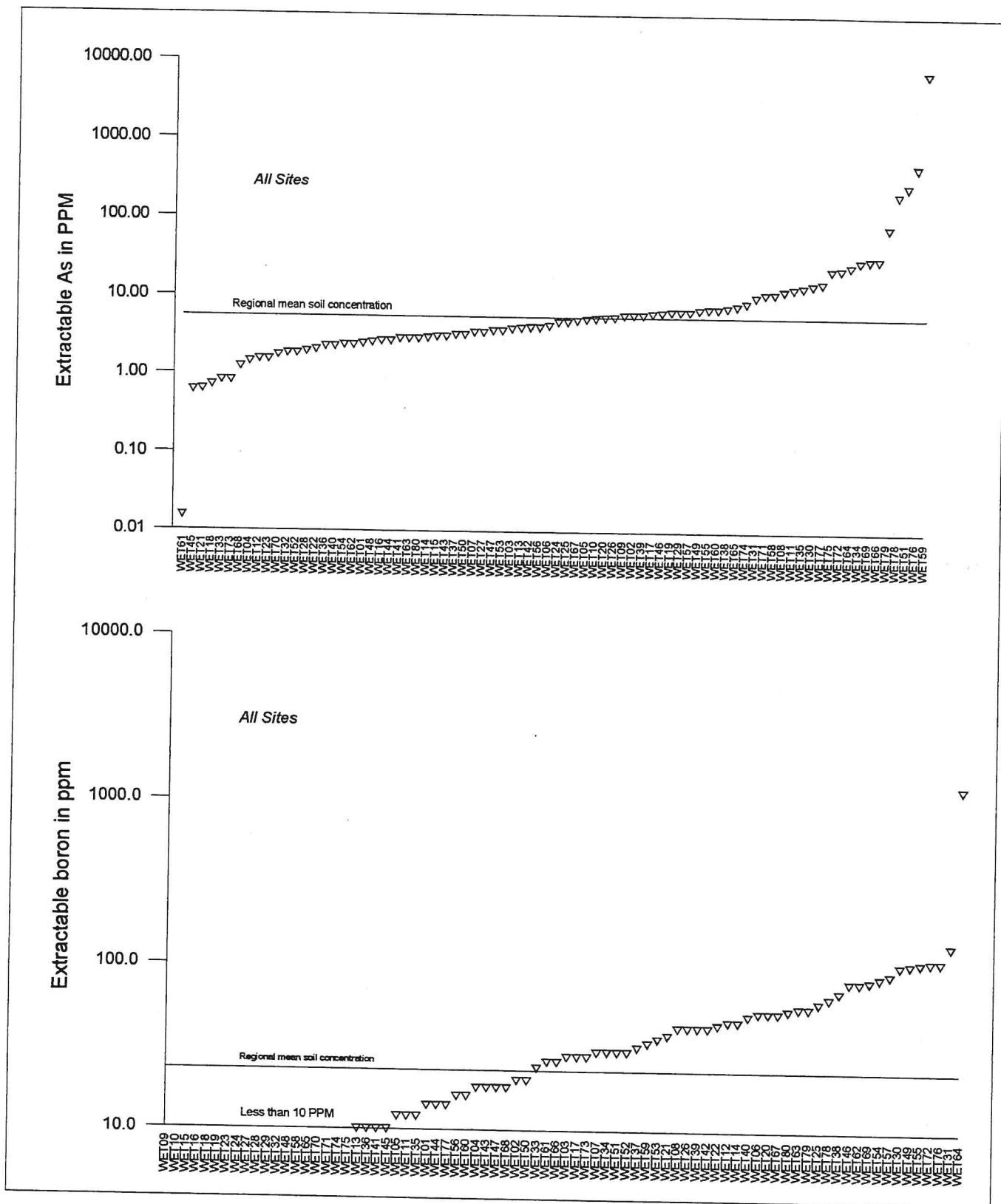


Figure 17. Concentrations of extractable arsenic and boron in sediments of the DEQ wetland characterization sites.

sites impacted by mine drainage or mineral processing waste. Sample sites in the central and eastern Montana plains show extractable sediment boron concentrations up to the 100-200 ppm range. Forty-three of the samples exceeded the regional mean soil concentration for boron, 22 of them by more than a factor of one geometric deviation.

Extractable vanadium concentrations (Figure 18) are distributed similarly to the boron data. Sediment samples from western sampling sites were below 20 ppm unless impacted by mine drainage or wastes, or associated with areas of known anomalous mineralization. The Schrammeck and Jarina WPA sites, underlain by Cretaceous shales and sandstones, again plot in the 20-100 ppm range with the impacted and naturally mineralized sites. Only one sample exceeded the regional geometric mean for total soil concentration.

Selenium concentrations up to about 1 ppm were reported from both reference and impaired sites of widely varying water chemistry across the state (Figure 18). The only reported value significantly above 1 ppm comes from a site (Warm Springs Pond #1) heavily impacted by mine wastes. Selenium concentrations do not show a pattern of elevation in mine-impacted wetlands other than the Warm Springs Ponds, however. The western Montana wetlands sampled were more likely to show concentrations above the .2 ppm detection limit than were central and eastern sites; many western sites with reported selenium concentrations are dilute, unimpaired sites not associated with areas of anomalous mineralization, while many sites impacted by mine drainage or mine wastes did not show detectable selenium in sediments. In eastern Montana, most analyses were below the detection limit; those sites with reportable values do not seem to bear any obvious relationship to salinity or pH of the water column or to geologic setting, although most are basins closed to surface water outflow. Overall, 25 samples show extractable selenium concentrations exceeding the regional geometric mean for total selenium, 10 by more than one geometric deviation.

Extractable nickel and chromium concentrations above the detection limits of 10 ppm are seen with highest frequency in sample wetlands of the southern (unglaciated) Montana plains (Figure 19). Glaciated plains sites also often show nickel and chromium concentrations in the 10 to 30 ppm range. In sample wetlands in western Montana, extractable chromium or nickel concentrations above 10 ppm are typically associated with mining impacts or areas of known mineralization, unless underlain by Cretaceous sedimentary rocks more typical of eastern Montana settings (the Jarina and Schrammeck Lake WPAs). Exceptions include the Ninepipe pothole (nickel) and Wagner Basin (nickel and chromium) sample sites. Overall, 17 extractable nickel analyses and two extractable chromium analyses exceeded the regional geometric mean (total) soil concentrations; only four nickel



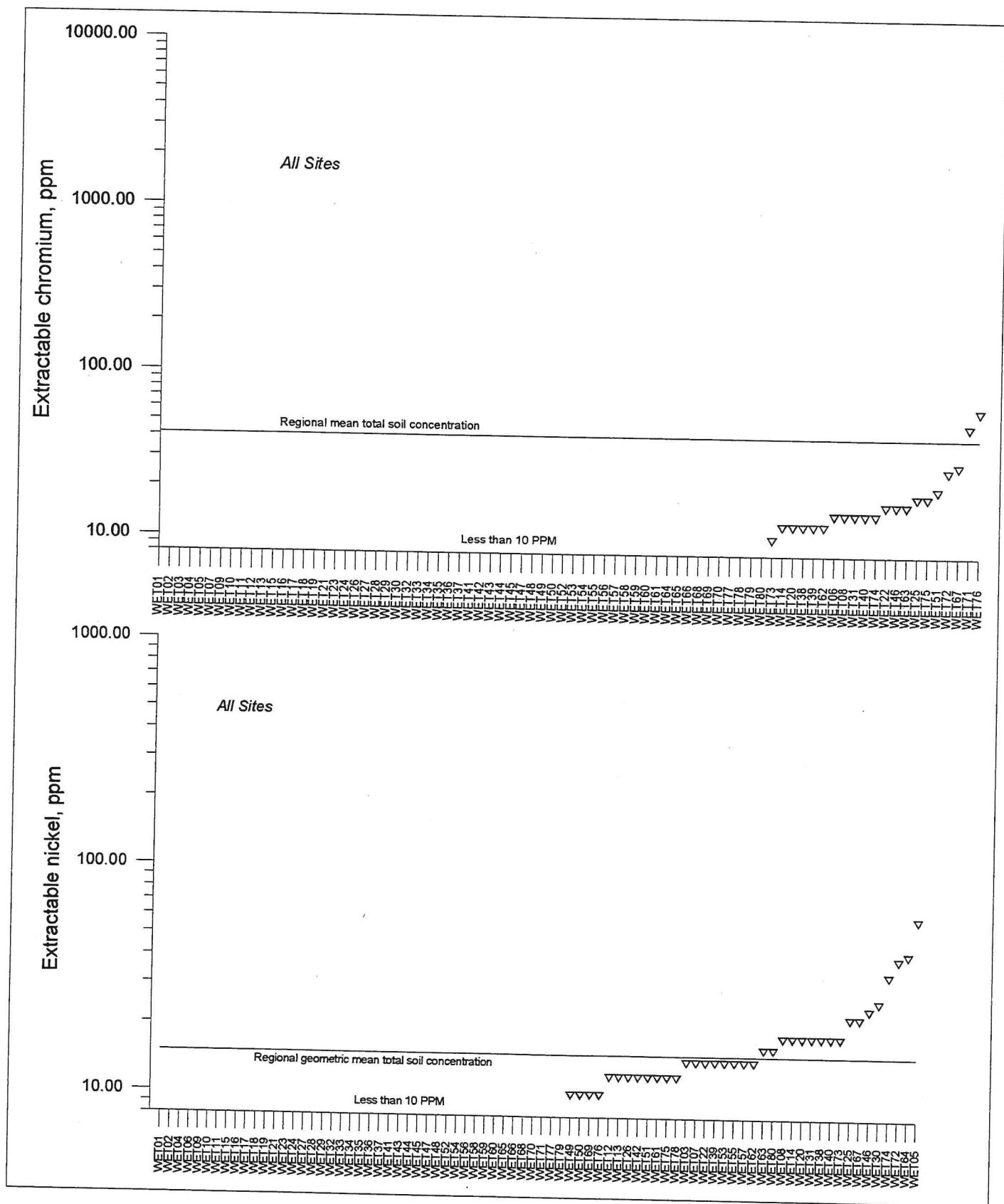


Figure 19. Extractable chromium and nickel concentrations in sediments of the DEQ wetland characterization sites.

concentrations exceeded the mean value by a factor of one geometric deviation or more.

Extractable copper and zinc concentrations above the detection limits (10 ppm for both elements) are widespread across the wetland sample set in wetlands of all hydrologic and geologic settings (Figure 20). Copper concentrations are below 50 ppm except in wetlands subject to the effects of mining and transportation corridors; two sample sites contaminated by mine drainage and mineral processing waste approach 1000 ppm in extractable copper. Considering only sites which are not impacted by mining, wetlands with high water-column pH (above 9) show a generally lower range of concentrations than sites with near-neutral pH. Overall, twenty-four extractable copper analyses exceeded the geometric mean of total soil copper for the western U.S.; nine of these exceeded the mean by factors of one geometric deviation or more.

Extractable zinc concentrations are generally near or below 100 ppm unless effected by mining, mineral processing, or transportation corridors (Figure 20). Sample sites impacted by mine drainage and mineral processing waste range up to several thousand ppm extractable zinc. As with sediment copper concentrations, zinc concentrations in unimpacted sites appear to be generally higher in wetlands with near-neutral to moderately alkaline water-column pH than in high-pH sites. Thirty-two of the samples exceed the regional geometric mean for total zinc concentrations in soil. Thirteen exceed the mean by more than a factor of one geometric deviation.

Several of the trace elements selected for analysis occur above analytical detection limits mainly in wetlands subject to cultural impacts or in areas of mineralized geology. Cadmium concentrations (not shown) above detection limits (10 ppm) are reported for only three sites in the sample set, all impacted by mining activities. Extractable lead concentrations (not shown) exceed the detection limit (also 10 ppm) at only 11 sites, ranging up to more than 3000 ppm. The four highest lead concentrations are reported from mine-impacted sites, and most of the rest are subject to influences from transportation corridors or areas of mineralized geology. Mercury concentrations (not shown) at or above the detection limit of .04 ppm occur in several reference sites; these are barely above detection, however, and the three sites showing somewhat higher concentrations (up to 1.52 ppm) are all impacted by mining or mineral processing. Extractable cobalt was reported at modestly above the detection limit (10 ppm) from two mine-impacted sites, and at or near the detection limit in three other wetlands in north-central Montana.

Notably high extractable iron concentrations occurred in sediment samples from several sites impacted by mining or mineral processing (Figure 21). Comparatively low extractable iron and aluminum concentrations were found in a number of sediment samples

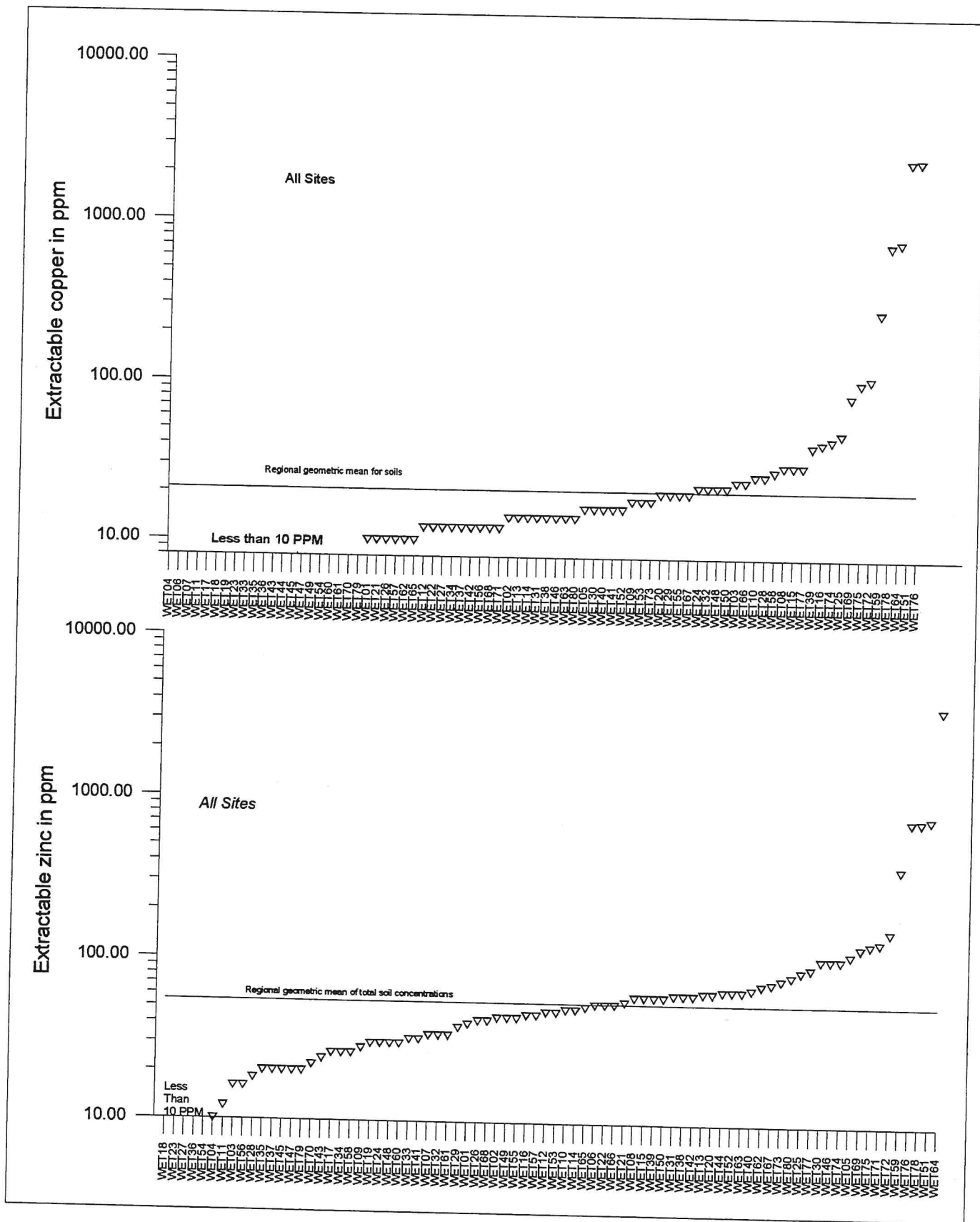


Figure 20. Concentrations of extractable copper and zinc in sediments of the DEQ wetland characterization sites.

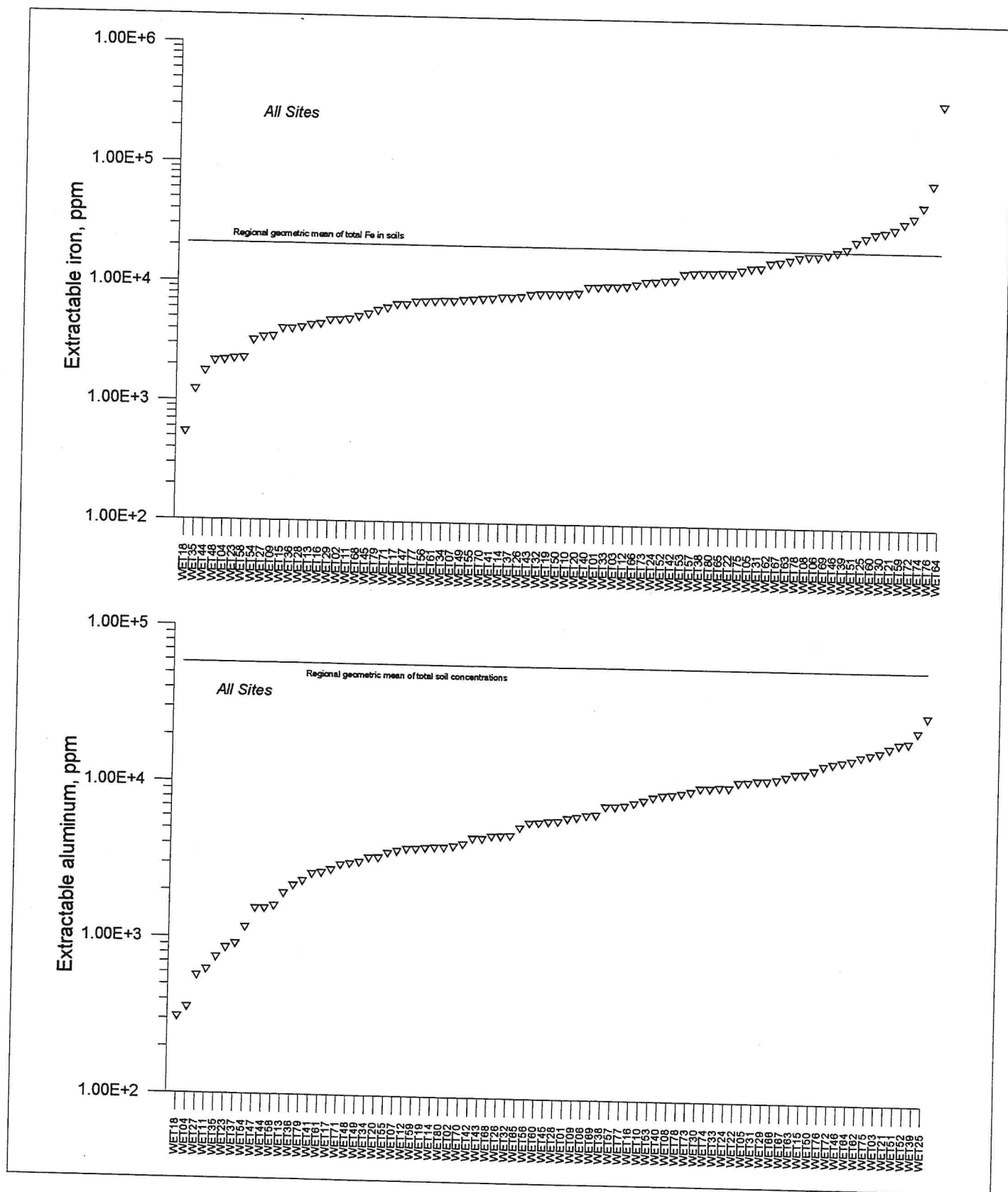


Figure 21. Extractable iron and aluminum concentrations in sediments of the DEQ wetland characterization sites.

from sites precipitating authigenic carbonate minerals.

Nutrients

Nutrient analyses included orthophosphate and (for most sites) total phosphorous concentrations; nitrate (plus nitrite), ammonia and total Kjeldahl nitrogen (TKN) concentrations; and total organic carbon concentration. All of these analyses were conducted on preserved, unfiltered samples.

Twenty-two of the 80 wetlands contained nitrate nitrogen above the .01 mg/l detection limit at the time of sampling (Figure 22). Most of these were only slightly above the detection limit. Only two sites (Benton and Warhorse lakes) exceeded .1 mg/l nitrate plus nitrite. Benton Lake, the only site exhibiting nitrate in excess of 1 mg/l, receives inflow carrying high-nitrate irrigation return flows near the WET05 sampling site.

Fifty sites exhibited ammonia (mostly ammonium ion at the observed pH values) above the .01 mg/l detection limit at the time of sampling. Most of these sites were in the range of .01 to about .1 mg/l ammonia (Figure 22). Seven sites were notably higher in concentration, ranging from .38 to a high of 5 mg/l at the Lahrity Lake SW site. Six of the 7 high-ammonium results are from sites believed for geologic and geomorphic reasons to receive significant ground-water discharge; other such ground-water discharge sites show ammonia concentrations below .01 mg/l, however. Redox conditions favorable to ammonia stability appear to be broadly reflected in field measurements of dissolved oxygen, as shown by Figure 23. Concentrations exceeding 1 mg/l ammonia occurred only in sites exhibiting less than 6 mg/l dissolved oxygen; above about 8 mg/l dissolved oxygen, ammonia concentrations were below .2 mg/l.

Total kjeldahl nitrogen for the samples analyzed ranged from .2 to 18.6 mg/l, showing a broad positive correlation with specific conductance (Figure 23) and with ammonia concentrations .

Phosphorous concentrations reported for the 80 wetlands vary widely, with notably high values for many of the saline sites; several wetlands exhibit orthophosphate and total phosphorous concentrations in the 1 to 10 mg/l range. Orthophosphate and total phosphorous concentrations converge at high concentrations; in the most phosphorous-rich wetlands, most or all of the phosphorous load is represented in the orthophosphate fraction (Figure 24). Saline, high-pH sites generally exhibit higher concentrations of both orthophosphate and total phosphorous. High-pH but relatively dilute wetlands tend to show low orthophosphate concentrations compared to more saline wetlands of similar pH.

Although the highest orthophosphate and total phosphorous

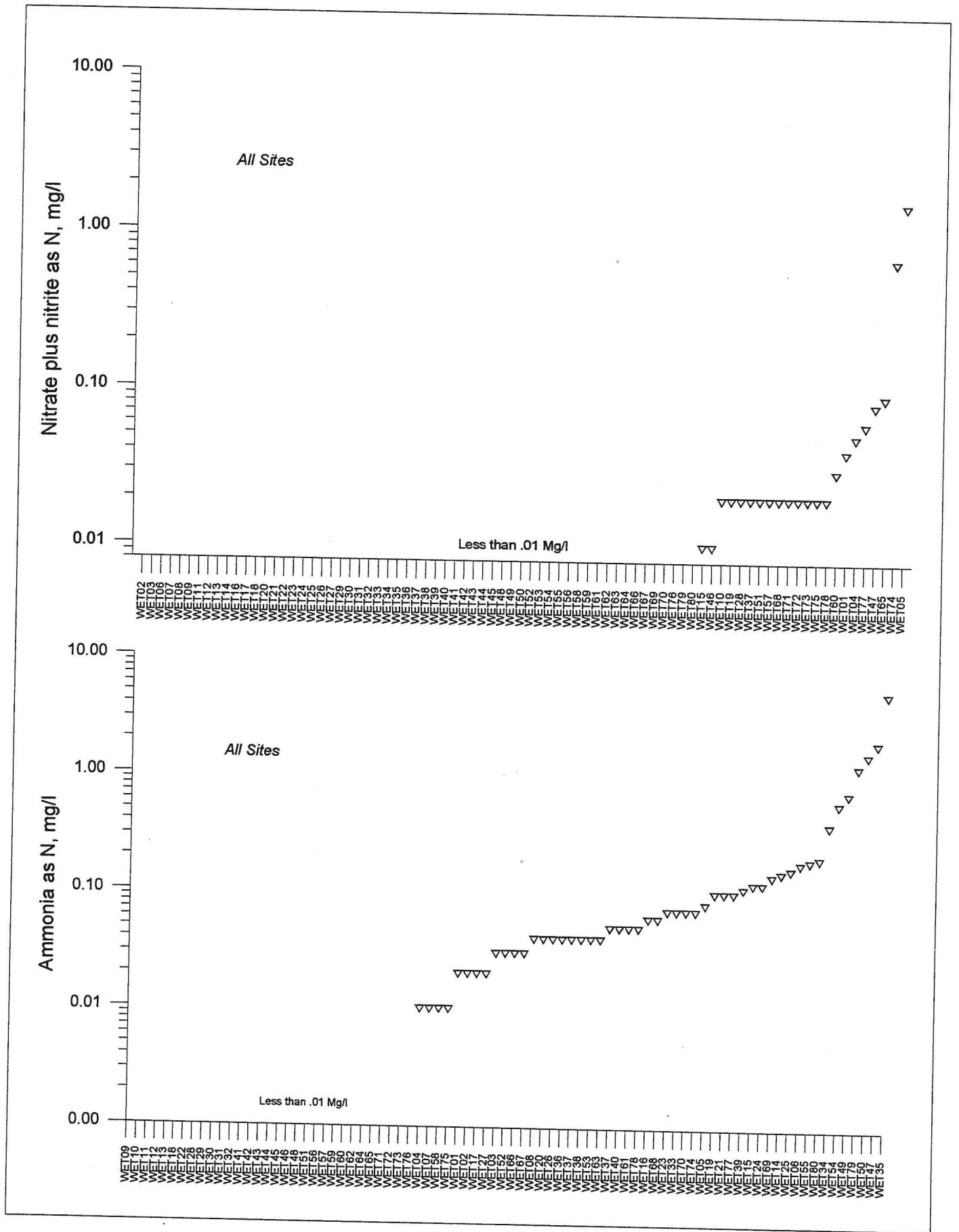


Figure 22. Nitrate and ammonia concentrations in the DEQ wetland characterization sites.

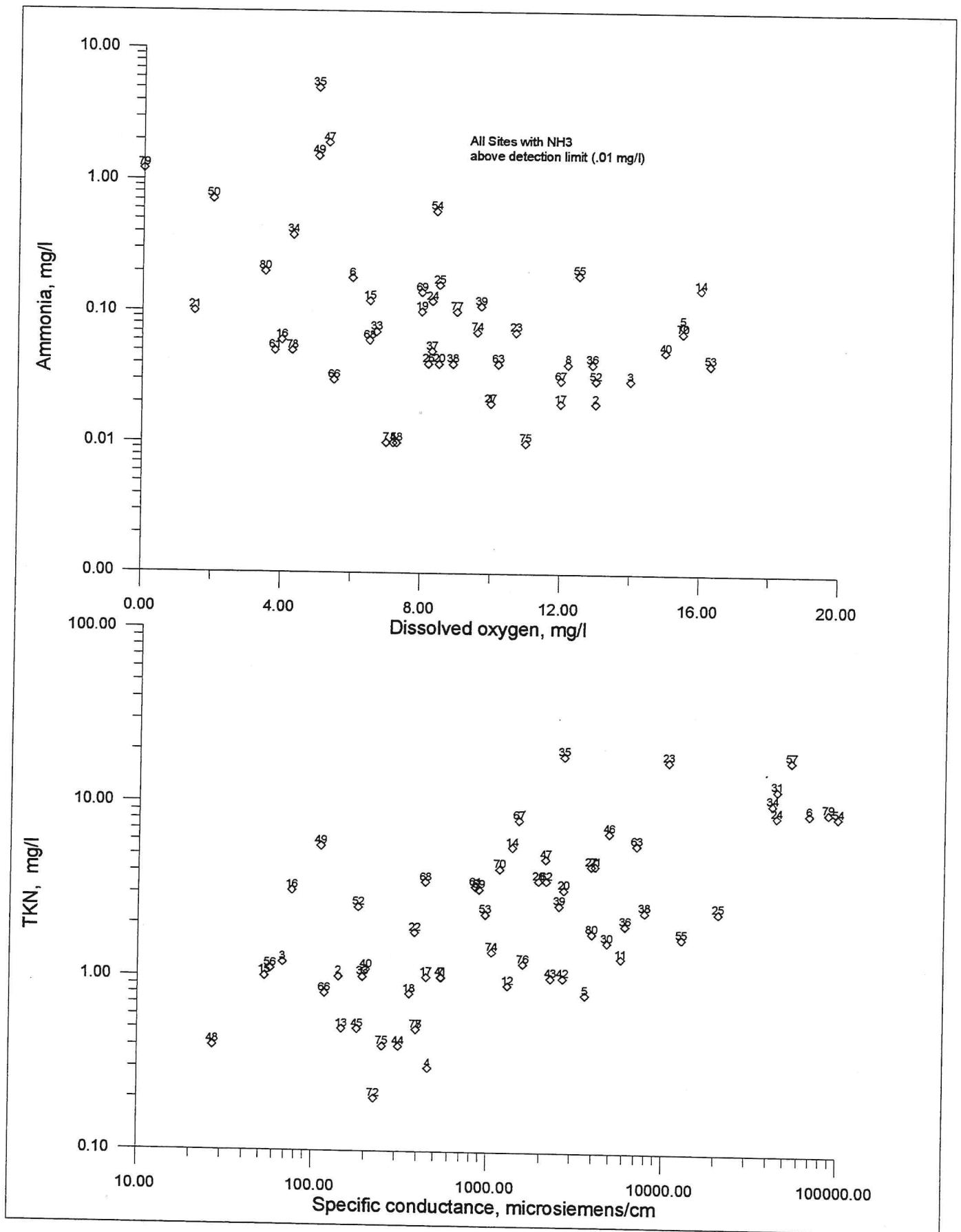


Figure 23. Ammonia and TKN concentrations plotted against (respectively) dissolved oxygen concentration and specific conductance

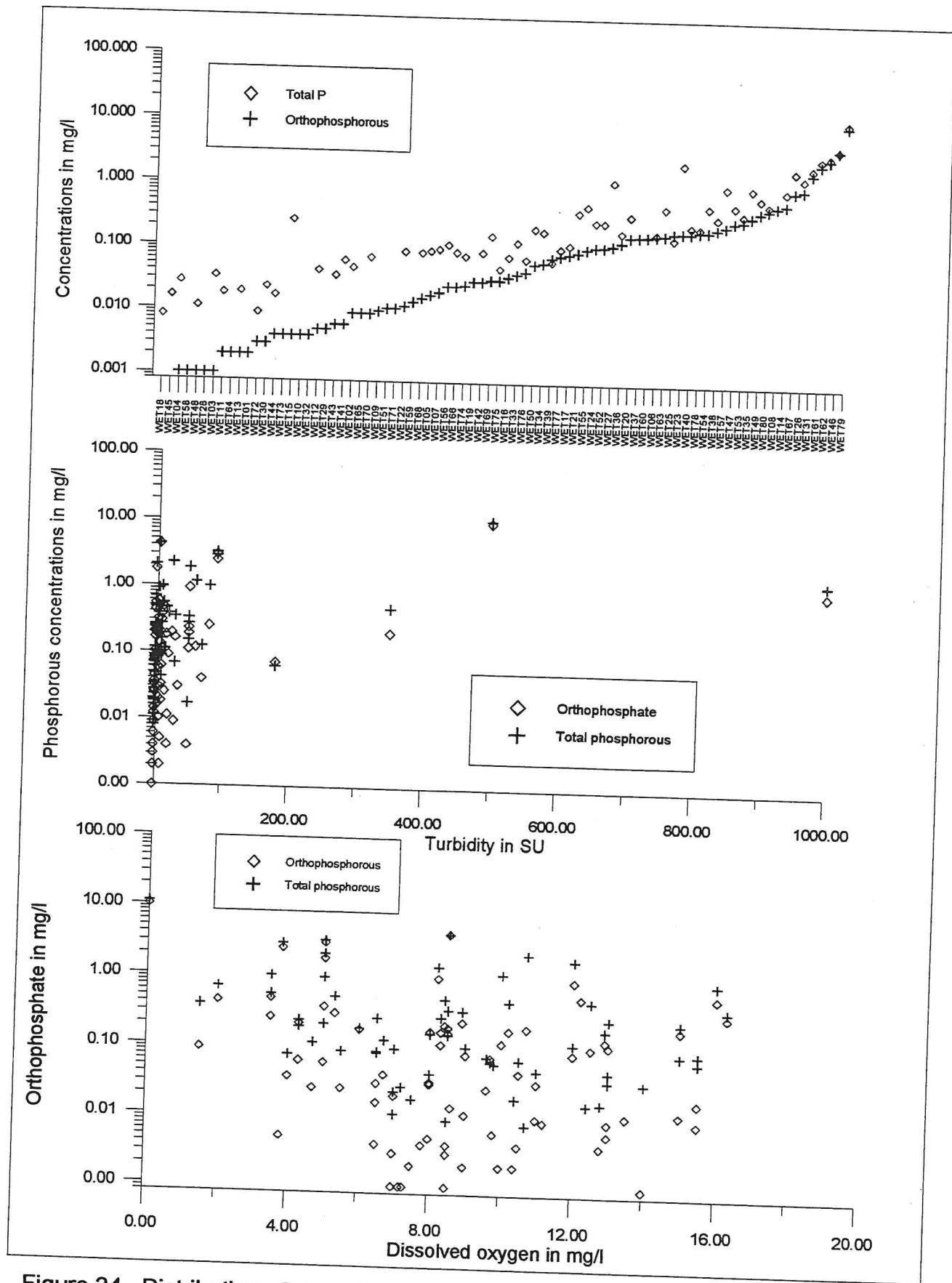


Figure 24. Distribution of phosphorous concentrations and plots of phosphorous against measured turbidity and dissolved oxygen.

values shown (White Lake) were from a very turbid sample, generally there does not appear to be a strong relationship between turbidity and phosphorous concentrations in these samples (Figure 24). High orthophosphate and total phosphorous concentrations are shown by several sites with low turbidity. Redox conditions are important in phosphorous solubility, but dissolved oxygen concentrations as measured for this study do not seem to correlate with (unfiltered) orthophosphate or total phosphorous (Figure 24).

Total phosphorous and orthophosphate concentrations show generally increasing relationships with both total organic carbon and with TKN (Figure 25) but do not show obvious relationships with nitrate or ammonia concentrations.

As with other trace constituents, mineral equilibria for phosphorous phases were not calculated, since dissolved analyses of aqueous forms were not performed.

Total organic carbon (TOC) concentrations exhibited by the 80 wetlands ranged from less than 1 mg/l to 218 mg/l (Figure 26). Within this sample set, low TOC values (below about 3 mg/l) occur in about 10% of the sample sites within a relatively narrow range of intermediate salinity from 200 to 2000 microsiemens/cm (Figure 26). Relatively high TOC values (greater than about 50 mg/l), though biased toward saline sample sites, occur across a wide range of wetland conditions reflecting almost the entire range of salinity and pH in the sample set. Almost all of the high-TOC sites share the characteristic of surface water closure (lack of outlets). TOC concentrations have an obvious positive correlation with TKN and a less well-defined relationship with phosphorous concentrations.

Organic sedimentary material observable in these divergent sites ranges from peat in the dilute, mildly acidic sites to gyttja-like sediments of probable algal origin in saline lakes. Presumably, the TOC reported for the sampled wetlands represents a diverse array of organic compounds reflecting differences in wetland chemistry, productivity and biota.

Classification

Ecoregions such as those of Omernick (1986) integrate regional environmental characteristics, and provide one approach to wetland classification. Geomorphic characteristics provide a basis for systems of wetland classification which group sites with similar hydrologic functions. The provisional classification used here for the DEQ characterization sites is based on the premise that both local geomorphic and regional geologic and climatic characteristics are necessary to explain the observed variability in water quality. Classification according to measured chemical parameters is avoided here, as one of the objectives of classification in this case is

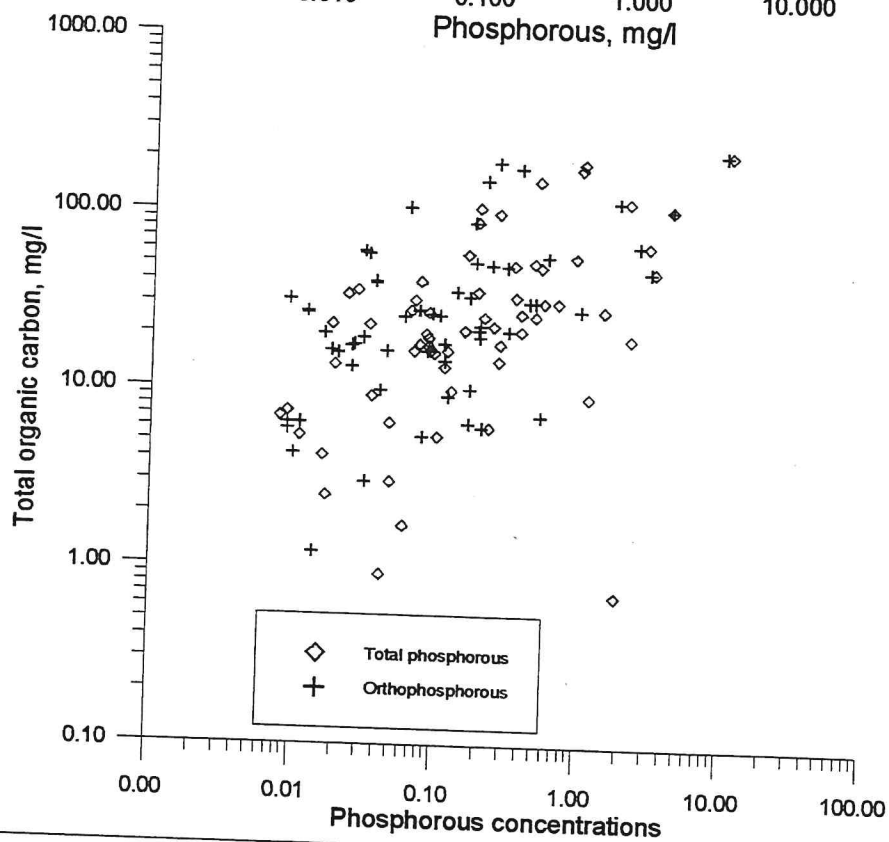
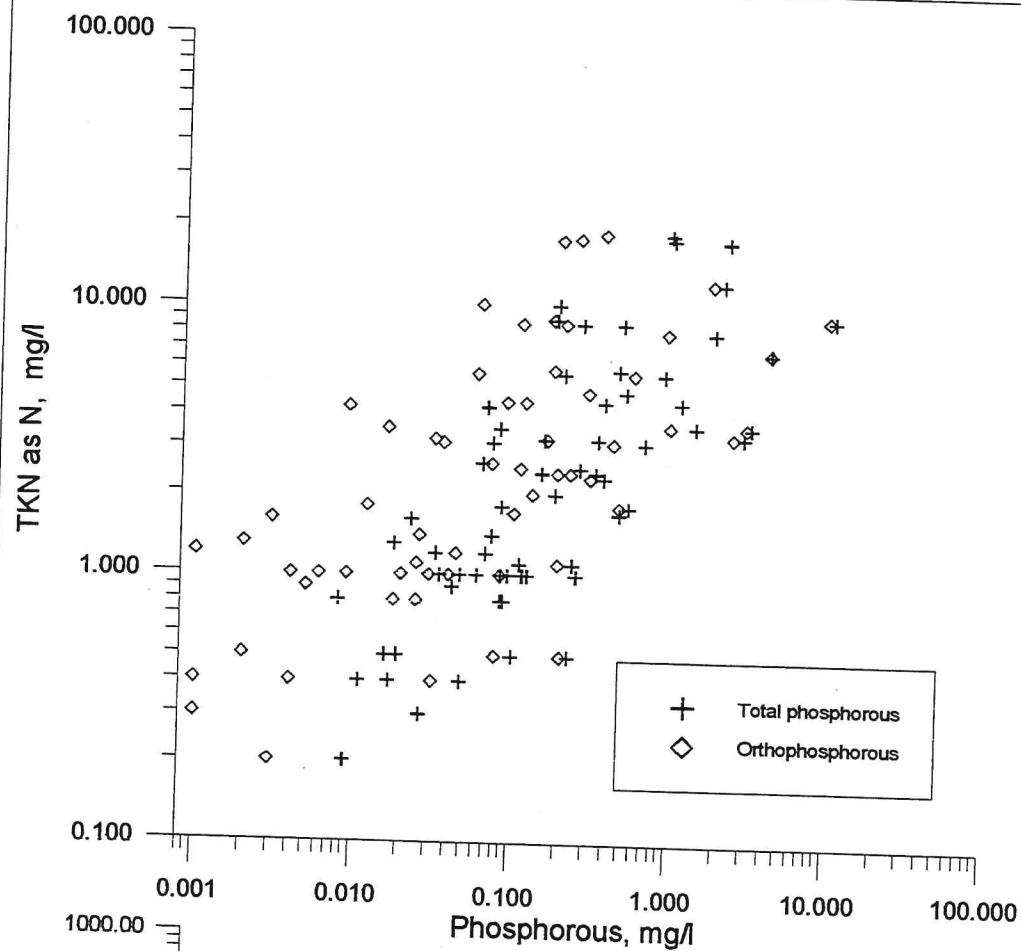


Figure 25. Phosphorous concentrations plotted against total kjeldahl nitrogen and total organic carbon concentrations.

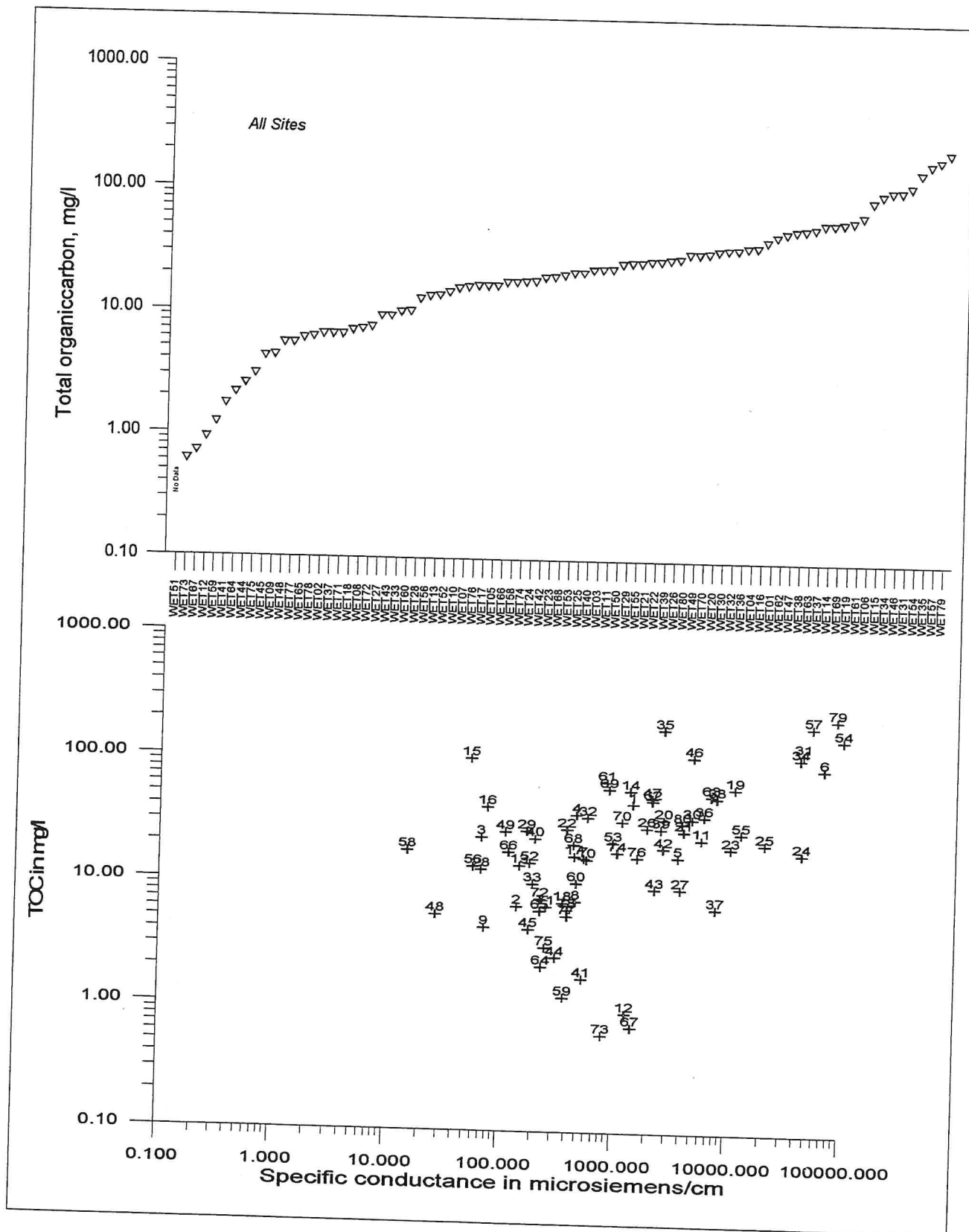


Figure 26. Distribution of total organic carbon concentrations and relationship to specific conductance for the DEQ wetland characterization sites.

to provide some power to predict water chemistry. As a provisional classification of a nonrandomized sample set, this scheme was not subjected to statistical evaluation. Rather, it serves as a conceptual starting point for more rigorous classification.

Figure 27 shows the criteria applied and Table 2 shows the resulting grouping of the sample sites with selected physical and chemical characteristics. Site types 1** are distinguished from site types 2** by "lotic" and "lentic" hydrologic affinities following the terminology of Cowardin et al (1979). Site types 1** include wetlands fitting Brinson's (1993) "riverine" and "extensive peatland" classes. Site types 2** include sample sites within Brinson's "depressional" and "fringe" hydrogeomorphic classes.

Wetland types 1** are further subdivided on the basis of climatic and regional geologic setting. Class 11 includes sites with high "net precipitation" according to the MAPS values used in the geoclimatic database. (MAPS "net precipitation" values for these sites are all -4 inches or greater.) Close correlations between precipitation and elevation in mountainous western Montana mean that this class also represents the topographically highest subset of the sampled wetlands. Class 12 includes all other "lotic" sites west of the continental divide. Classes 13 and 14 include all "lotic" sites east of the continental divide, provisionally subdivided into glaciated and unglaciated geologic settings, in the manner of Omernick (1986).

The presence or absence of surface drainage has been shown to be a significant variable in lake classification (Winter, 1977), and is inferred to have a significant bearing on wetland water chemistry in evaporative settings because of the influence drainage has on water and solute mass budgets. Class 2** ("lentic" wetlands of Cowardin, "depressional" and "fringe" classes of Brinson) is subdivided into wetlands closed with respect to surface water drainage (classes 21*), and those with mapped or inventoried surface outlets (classes 22*). This distinction is not meant to imply anything about groundwater interactions with the sampled wetlands; in fact, many of the wetlands considered closed with respect to surface water can be inferred by water chemistry to have significant groundwater outflows. A few of the sampled wetlands with mapped outlet streams are inferred through field observations or interviews to have had no surface outflow for extended periods (more than 10 years) prior to sampling (e.g., Alkali Lake and Hailstone Reservoir). These are classified with wetlands closed to surface water outflow.

As with the lotic wetlands, lentic wetlands with surface water closure are further subdivided on the basis of climatic characteristics and regional geologic setting. Class 211 includes the closed lentic sites with the highest MAPS "net precipitation"; these wetlands are also characterized by their relatively high

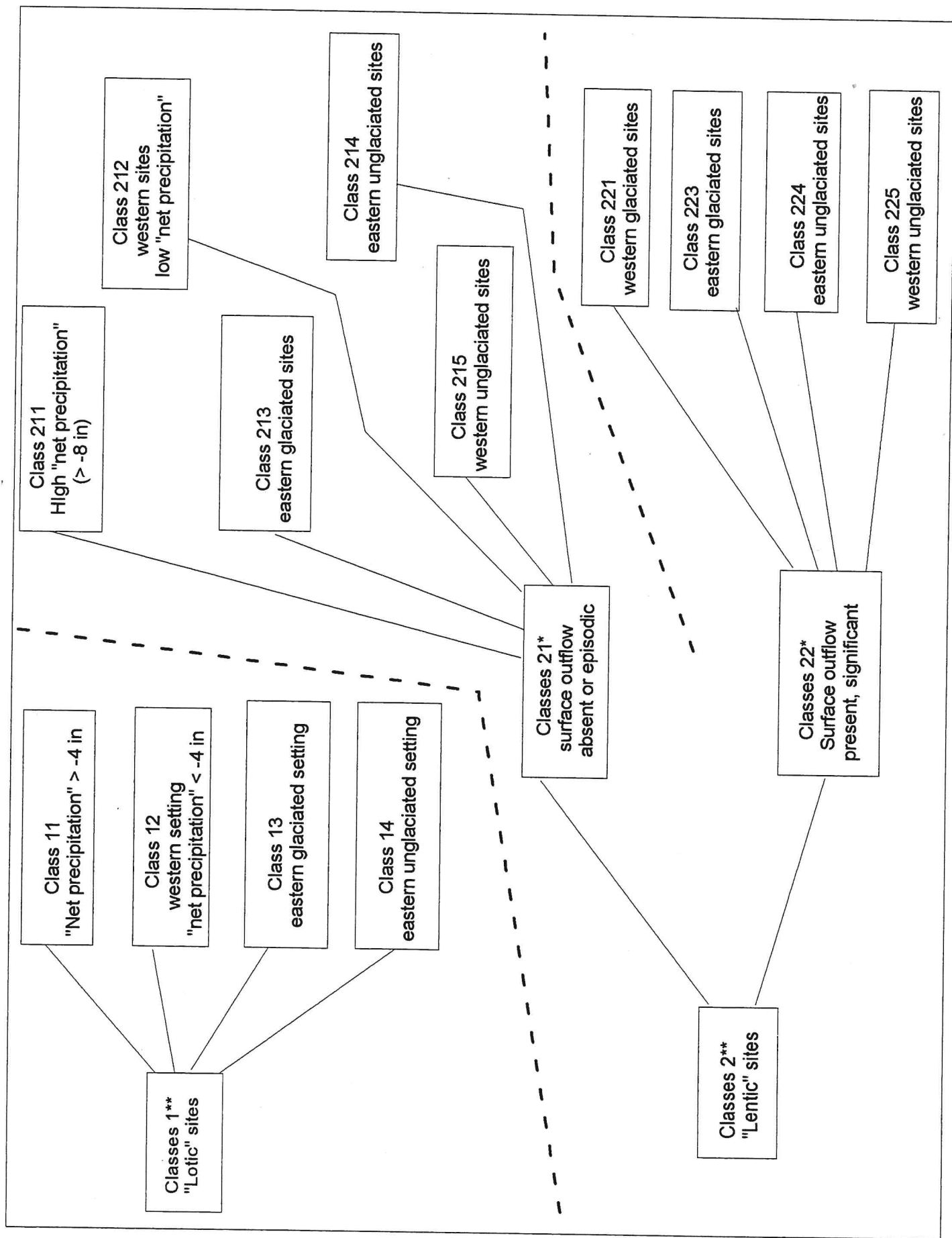


Figure 27. Provisional geoclimatic classifications for the DEQ wetland characterization sites.

Site Code	Provisional class	Elevation	Basin relief	Specific conductance	pH	Ca as % cations	Mg as % cations	Na as % cations	Alkalinity as % of anions	Sulfate as % anions
WET29	11	6035	738	169	6.9	0.60	0.28	0.09	0.97	0.00
WET56	11	7875	595	57	5.5	0.21	0.00	0.65	0.58	0.33
WET58	11	6970	155	15	4.9	0.57	0.00	0.43	0.00	1.00
WET59	11	6960	570	370	3.63	0.52	0.26	0.18	0.00	1.00
WET66	11	7020	105	117	6.0	0.61	0.23	0.12	0.49	0.46
WET72	11	8470	2030	225	7.8	0.73	0.22	0.04	0.93	0.06
WET03	12	4275	190	67	6.9	0.41	0.39	0.18	1.00	0.00
WET04	12	3980	2024	460	7.4	0.72	0.25	0.02	0.97	0.03
WET09	12	6610	1987	72	6.34	0.62	0.00	0.27	1.00	0.00
WET33	12	3800	2152	192	7.2	0.62	0.28	0.08	0.90	0.00
WET44	12	3550	2085	310	7.7	0.72	0.25	0.02	0.95	0.00
WET51	12	4820	2542	334	7.86	0.60	0.24	0.16	0.78	0.22
WET64	12	5165	2332	235	6.63	0.53	0.40	0.07	0.23	0.75
WET65	12	3095	2190	225	7.88	0.75	0.24	0.01	0.87	0.13
WET73	12	4550	3118	815	7.98	0.66	0.33	0.01	0.31	0.69
WET07	13	2673	3648	540	8.4	0.20	0.19	0.57	0.83	0.14
WET60	13	4610	402	465	8.06	0.68	0.30	0.02	0.94	0.06
WET12	14	2170	562	1300	8.6	0.16	0.38	0.45	0.62	0.37
WET43	14	3560	298	2280	8.7	0.15	0.14	0.71	0.28	0.68
WET80	14	2338	62	3900	7.7	0.16	0.20	0.62	0.43	0.50
WET13	211	8015	270	147	6.9	0.65	0.27	0.07	0.86	0.11
WET15	211	3740	60	53	6.1	0.54	0.26	0.15	0.71	0.23
WET16	211	3745	55	75	6.1	0.46	0.33	0.13	0.94	0.00
WET48	211	5750	350	27	5.5	0.17	0.00	0.65	0.51	0.00
WET50	211	1935	473	109	6.2	0.16	0.12	0.48	0.39	0.00
WET01	212	2982	228	1430	9.52	0.01	0.71	0.26	0.74	0.24
WET19	212	4190	140	11200	9.5	0.00	0.22	0.69	0.35	0.55
WET34	212	4145	295	41600	9.7	0.00	0.21	0.59	0.08	0.84
WET53	212	2970	35	960	9.4	0.09	0.84	0.04	0.87	0.01
WET68	212	2537	668	435	7.8	0.25	0.63	0.09	0.95	0.00
WET70	212	3030	235	1150	9.9	0.02	0.76	0.20	0.95	0.02
WET05	213	3620	330	3600	9.13	0.12	0.52	0.35	0.05	0.90
WET11	213	1956	66	5760	9.3	0.00	0.29	0.69	0.43	0.55
WET14	213	2169	151	1350	9.1	0.23	0.31	0.39	0.52	0.41
WET22	213	4135	86	380	8.5	0.49	0.30	0.03	0.90	0.05
WET30	213	4675	90	4770	7.8	0.23	0.60	0.15	0.05	0.94
WET46	213	3315	1089	4840	8.4	0.15	0.41	0.42	0.24	0.73
WET54	213	2049	71	99000	9.75	0.00	0.01	0.97	0.40	0.38
WET55	213	2169	186	12800	8.72	0.03	0.07	0.89	0.14	0.84
WET57	213	3445	60	53300	9.6	0.02	0.44	0.53	0.01	0.86
WET61	213	2570	480	840	7.7	0.21	0.26	0.46	0.83	0.12
WET79	213	1951	71	87000	10.0	0.00	0.01	0.98	0.23	0.72

Table 2. Provisional geoclimatic classes with selected physical and chemical characteristics.

elevation and by small size and low basin:wetland area ratios. Class 212 includes all other closed lentic wetland sites of western Montana which are underlain by glacial deposits; these are provisionally distinguished from class 215 (western closed lentic wetlands underlain by nonglacial deposits) on the basis of their distinct processes of formation. Classes 213 and 214 include closed lentic systems of the Great Plains, underlain respectively by glacial and nonglacial materials. Included within these classes are two sites (the Jarina WPA and Schrammeck Lake) which are within the boundaries of the Rocky Mountain Ecoregion of Omernick (1986), but have geologic affinities with eastern Montana.

Lentic wetlands with surface water outlets are further divided into four classes reflecting glaciated and unglaciated settings in western Montana and in the Great Plains.

Figures 28 through 30 provide a qualitative test of the predictive usefulness of this provisional classification with respect to major-ion water chemistry. Class 11 covers a broad range of compositions, with a field extended to high-sulfate compositions by the impaired Ontario Mine wetland and by the Ontario Headwaters sample, which may reflect natural influences of mineralized geology (and is also subject to a large analytical charge-balance error). High variability within this provisional class reflects in part impairment, and probably in part the diverse geology of mountain wetland sites.

Class 12 sites occupy a restricted field of cation distribution, but the anion field covers a broad range. High-sulfate compositions are represented by both Swamp Gulch (a highly impaired site) and by Wagner Basin, an unimpaired wetland supported by naturally sulfate-enriched groundwater discharge. In this case, the proposed classification is not effective in distinguishing impacted major-ion water chemistry from natural variability within a class. Trace element occurrences are distinctly different for these two sites, however.

Classes 13 and 14 are considered too small to evaluate.

In provisional class 211, a large part of the major-ion variability is accounted for by the Mikillop Creek site, which is believed to be influenced by discharge from a bedrock groundwater flow system (see Appendix A), and by Mary's Frog Pond, where the accuracy of the analysis is uncertain due to dilute water chemistry and a large analytical charge balance error. As with Wagner Basin, the Mikillop Creek analysis illustrates that groundwater discharge from deep flow systems may diminish the predictive capability of this classification.

Provisional classes 212 and 213 both display wide diversity in major-ion water chemistry and in salinity. The Piper diagram

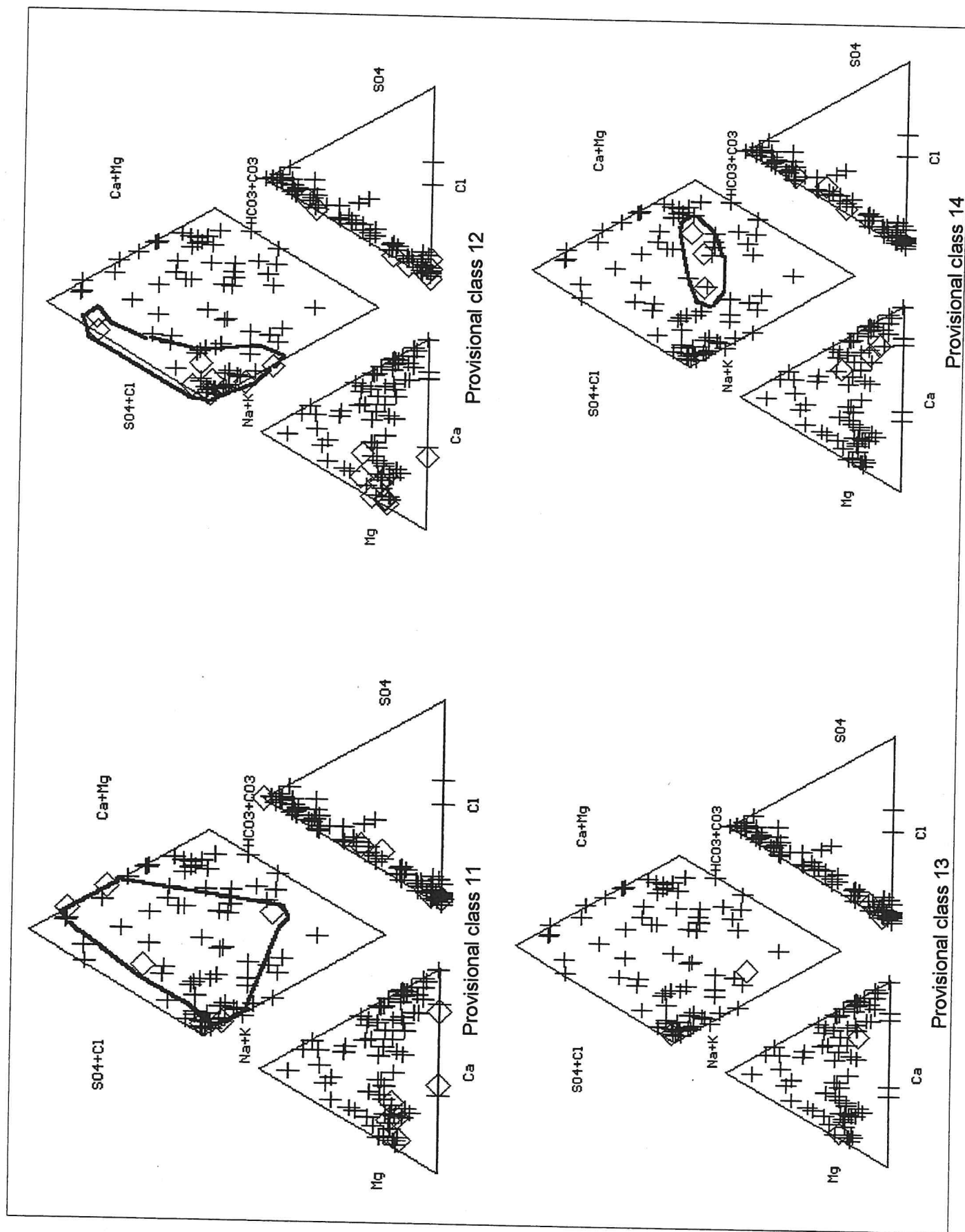


Figure 28. Piper diagrams of major-ion water chemistry for the provisional "lotic" wetland classes .

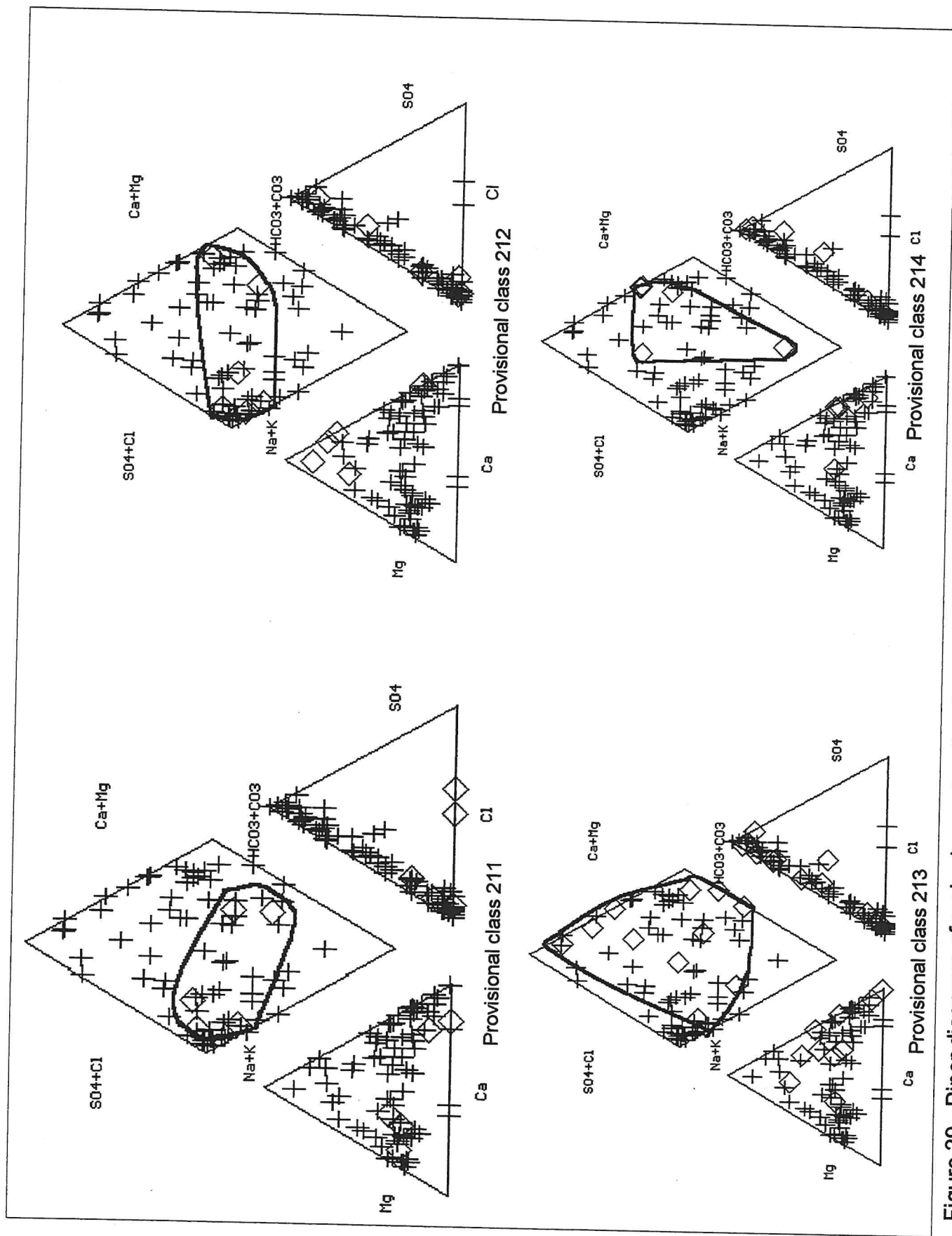


Figure 29. Piper diagrams of major-ion water chemistry for the provisional "lentic" wetland classes with surface outflow absent or episodic (class 215 not included).

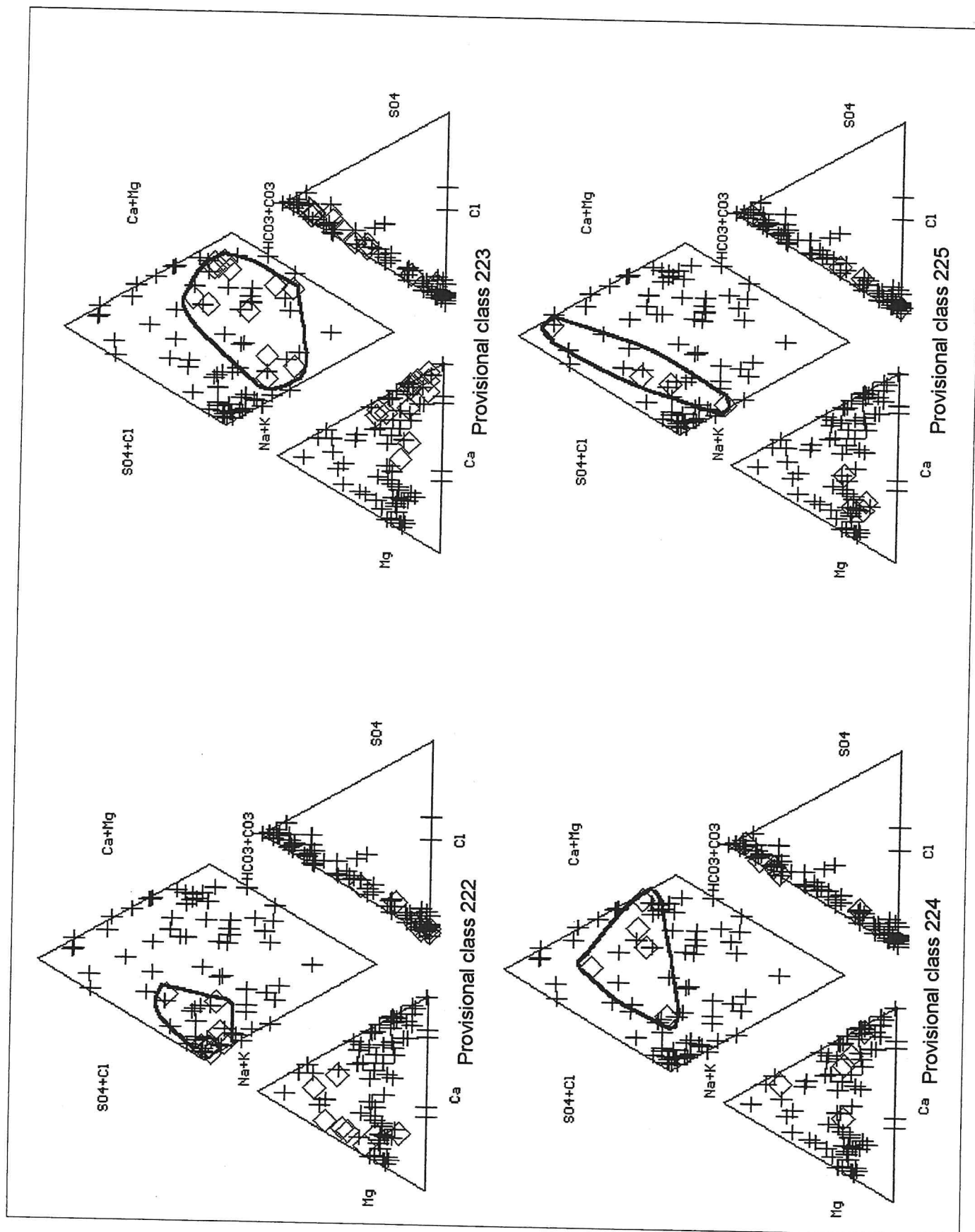


Figure 30. Piper diagrams of major-ion water chemistry for the provisional "lentic" wetland classes with frequent or perennial surface outflow.

field describing class 212 (western closed glaciated basins) water chemistry is nearly contained within the 213 (eastern closed glaciated basins) field. The wide array of water chemistry seen within these classifications indicates the need to identify local controls over chemical mass balances (particularly groundwater relationships) in settings of this type.

Provisional class 214 incorporates a wide range of salinity and major-ion water chemistry. The three most saline sites, however, have evolved nearly identical chemical compositions. The most dissimilar site (Schrammeck Lake), defining most of the variability in chemistry within this class, has a sodium-carbonate composition unique among the sampled wetlands.

Provisional class 222 (western lentic wetlands with surface outflows) displays a relatively narrow range of major-ion chemistry similar to provisional class 12 without the high-sulfate outriders discussed above, and distinct from eastern wetlands with surface outflow. Provisional classes 223 and 224 (glaciated and unglaciated eastern wetlands with surface drainage) seem, in turn, to define distinct though overlapping geochemical fields. Provisional class 225 exhibits a wide range, overlapping various other fields, which is defined almost entirely by the distinct anionic compositions of the three Warm Springs treatment ponds.

The provisional classifications suggested here provide some qualitatively useful distinctions in major-ion water chemistry between several of the wetland classes. In some cases, impaired sample sites are identifiable as outriders to the combined cation/anion fields defined by apparently unimpaired sites with which they are classed. In these cases, water chemistry fields defined on the basis of only unimpaired sites would appear better defined than those shown here.

Classes incorporating closed-basin glacial wetlands show broad diversity in major-ion composition and in salinity. Alone, these classifications are too inclusive to have predictive usefulness for water chemistry.

Much of the variability observed within these site classes can probably be attributed to their relative positions along groundwater flow paths and the influence of hydrogeologic position on chemical mass balance (e.g., Donovan, 1992; LaBaugh et al, 1987; Winter and Carr, 1980; Meyboom, 1967). In some cases, useful inferences can be drawn regarding hydrogeologic position on the basis of water chemistry, geologic setting and topographic position (see below and Appendix A). In a few cases, notably the Jarina and Schrammeck Lake WPA sites (WET30 and WET62), wetland waters have unusual characteristics apparently generated by atypical evaporative fractionation pathways (Eugster and Hardie, 1978).

Closed Basin Wetlands and Alkalinity

Preliminary DHES evaluation of the wetland characterization data resulted in closed basin sites of intermediate salinity from both western Montana and the Great Plains being grouped together in a single class. Referred to as "class 5" (Apfelbeck, in preparation), this group exhibits diverse biological and chemical characteristics. Distinctions in biological characteristics within this grouping appeared to relate in part to alkalinity, with several low-alkalinity sites displaying notably high indices of biological diversity and abundance in comparison to the more alkaline sites (Apfelbeck, in preparation). Factors controlling alkalinity and pH in closed basin lentic settings are thus of interest in evaluating the classification of wetland biological characteristics.

Investigations of evaporatively concentrated alkaline water bodies have identified important geochemical pathways describing the evolution of major solute concentrations and solid precipitates (see, for example, Hardie and Eugster, 1970; Eugster and Jones, 1979; Kelts and Hsu, 1978; Donovan, 1993). While other processes are also important in determining the water chemistry expressed in closed evaporative basins, mineral solubility and carbonate solubility in particular probably plays a primary role in determining the major-ion distribution, alkalinity and pH of this type of wetland (Eugster and Hardie, 1978).

"Class 5" Sites

The eleven sites included in the "Class 5" category have diverse chemical characteristics. Field conductivity ranged from 380 to 11,200 microsiemens/cm and field pH ranged from 7.6 to 9.9 (Table 3). Major-ion composition for these sites covers a broad range roughly correlating with concentration (Figure 31). The more dilute sites within this group tend toward magnesium-bicarbonate (and/or carbonate) composition, while the more saline sites generally tend toward sodium sulfate compositions. The Jarina WPA site is unique among these sample sites in its magnesium-sulfate composition and in its very high absolute concentration of dissolved calcium.

Among these sites, only the Furnell WPA has a calcium concentration approaching 50% of the total cation concentration in milliequivalents per liter, and only the Jarina site (with 404 mg/l dissolved calcium) exhibits a calcium concentration exceeding 50 mg/l. Five of these sites (Alkali, Brush, Evans, Gaffney and Turtle Lakes) exhibit low calcium concentrations (<10 mg/l) indicating removal of most dissolved calcium through carbonate precipitation. Although the Mallard Pond sample collected for this study exhibits a moderately high calcium concentration, this

Site code	Site name	Field pH	Specific cond.	Ca, mg/l	Mg, mg/l	Na, mg/l	K, mg/l	SO ₄ , mg/l	Cl, mg/l	HCO ₃ , mg/l	CO ₃ , mg/l	Total alk (lab)	Area, ac	Basin area, ac	Relief, ft
WET01	ALKALI LAKE	9.52	1430	3.4	183	129	18.2	378	28.7	414	536	950	100	560	228
WET11	BRUSH LAKE	9.3	5760	5.9	280	1260	71.6	2210	72.3	0	1070	1350	250	460	66
WET19	EVANS LAKE	9.5	11200	4.1	410	2450	515	3755	469	1256	884	2140	74	280	140
WET32	KLEINSCHMIDT LAKE	9.53	577	22	59.8	26.1	8.5	31	4.9	192	120	312	285	7350	3071
WET47	MALLARD POND	8.3	2100	47.6	108	327	1.6	466	30.2	0	146	797	17	160	40
WET53	NINEPIPE POTHOLE	9.4	960	25.7	151	15.2	15.2	7.4	50.9	0	316	390	0.1	3	35
WET69	TOWNSEND VALLEY	7.6	880	46.7	37.1	75.4	13.6	32.3	50.9	0	320	320	1.3	0	5
WET70	TURTLE LAKE	9.9	1150	8.2	165	84	7.6	20.6	27.1	0	754	807	7	200	235
WET22	FURNELL WPA	8.5	380	34.9	13.1	2.4	24.9	8.4	5.7	137	22	159	1.6	44	86
WET30	JARINA WPA	7.8	4770	404	624	304	42.6	3843	46.2	159	48	207	12	130	90
WET68	TOOLEY LAKE	7.8	435	25.7	38.5	9.9	5.9	0	10	106	126	232	29	860	668

Table 3. Selected chemical and physical characteristics of the closed-basin, oligosaline DEQ wetland characterization sites.

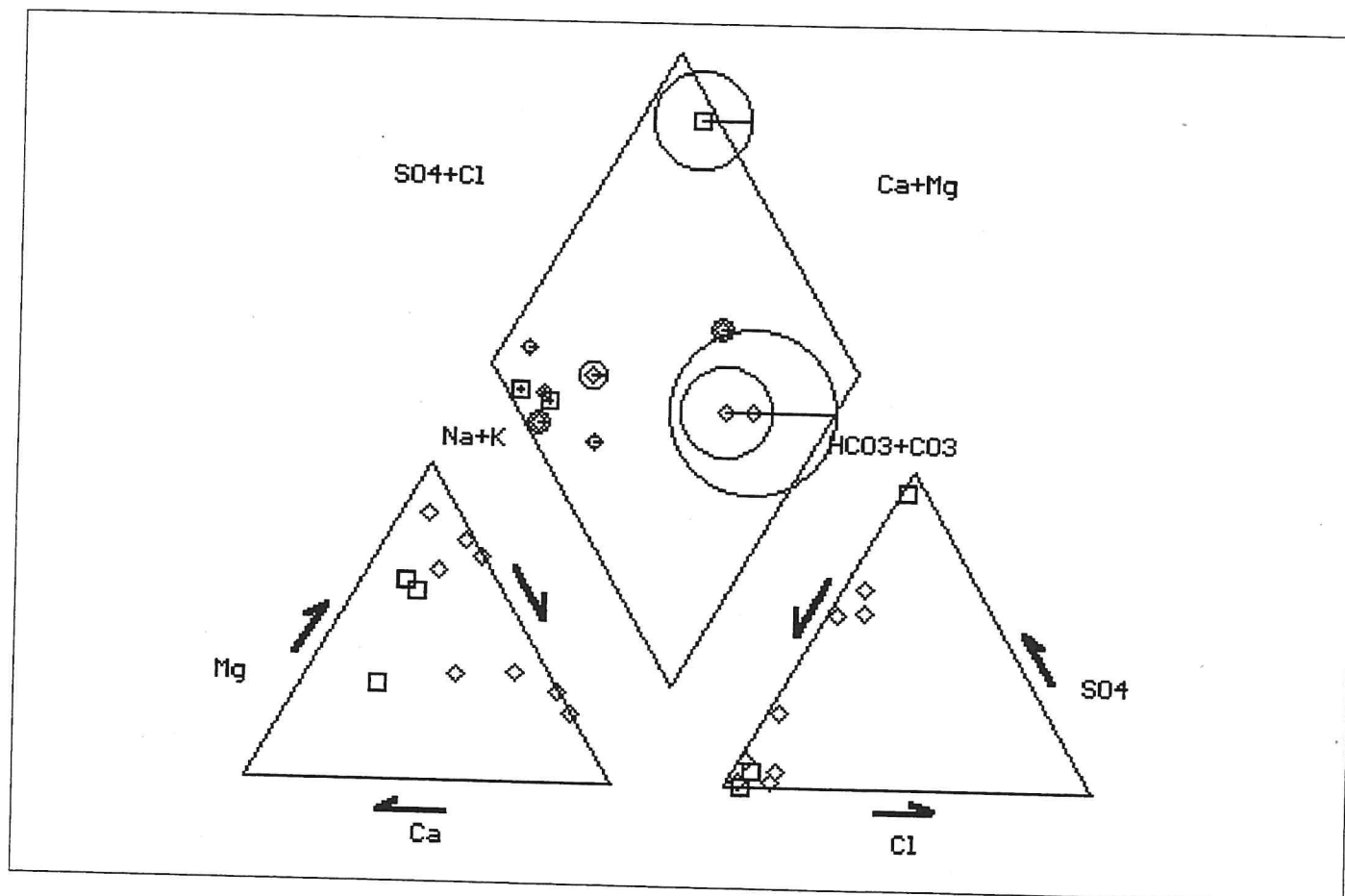


Figure 31. Piper plot of water chemistry of the closed-basin, oligosaline DEQ wetland characterization sites. Circles represent total dissolved solids concentrations.

wetland also exhibits apparent solubility-controlled depletion of calcium outside of the ground-water discharge area sampled at WET47 (see Appendix A and Reiten, 1991).

Total alkalinity (lab values) ranges from 159 mg/l to 2578 mg/l as CaCO_3 , and generally correlates with salinity; the notable exception is the Jarina WPA site, which is moderately saline but maintains comparatively low alkalinity. Unstable sample pH for many sites indicates the unreliability of lab determinations of bicarbonate to carbonate ratios; reported values of $\text{HCO}_3:\text{CO}_3$ range from 0 to about 6.

Composite scores from biological metrics are noticeably higher for three of the "class 5" sites than for the remainder of the group (Apfelbeck, in preparation). These three sites (Furnell and Jarina WPAs and Tooley Lake) appear to be distinguished chemically by their comparatively low alkalinities; total alkalinities reported for these sites were the three lowest in this classification. Comparatively low field pH and comparatively high bicarbonate to carbonate ratios are also notable, although these parameters overlap with some of the biologically lower-scoring "class 5" sites.

The comparatively low alkalinities common to the three higher-scoring sites reflect different geochemical origins distinguished by the dissimilarity in overall major-ion chemistry between the Jarina WPA sample and the Furnell and Tooley Lake samples. High alkalinities in many (if not all) of the other "class 5" sites reflect ground-water dissolution of carbonate minerals followed by depletion of calcium through precipitation of carbonate minerals and accumulation of CO_2 species. These biologically more "typical" "class 5" sites occur in evaporative settings, yet exhibit moderate salinities; in conjunction with their small drainage basins, these characteristics suggest groundwater dominance and flow-through positions along groundwater flow paths.

Unlike most of the "class 5" sites, Tooley Lake and the Furnell site exhibit low salinities and local topographic positions suggesting a dominantly recharge relationship to local ground-water systems. Tooley Lake is also underlain by deltaic sand which probably allows substantial groundwater outflow, substantiated by the significant springs reported discharging from these sediments along the Kootenai River (Appendix A). Ground-water inflow may represent only small water budgets components in Tooley Lake and the Furnell site, with CO_2 concentrations (and pH) in approximate equilibrium with the atmosphere.

At the Jarina site, the water composition is in near-equilibrium with gypsum (CaSO_4) as well as being somewhat oversaturated with carbonate phases. Unlike the other sites of this class, calcium concentrations on the order of 20 milliequivalents/liter substantially exceeds alkalinity

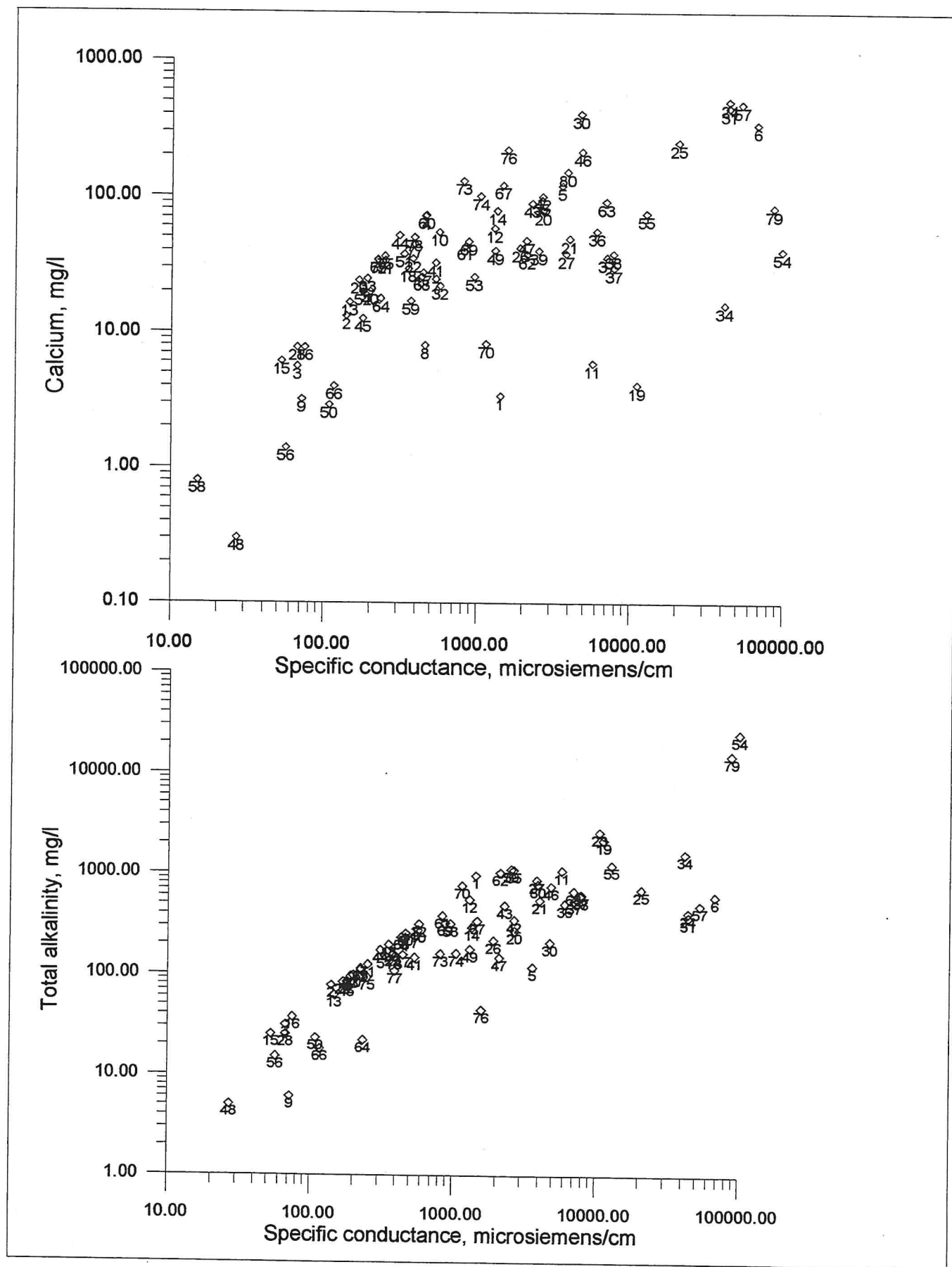


Figure 32. Calcium and alkalinity concentrations plotted against specific conductance.

(bicarbonate plus carbonate on the order of 4 milliequivalents per liter). Dissolution of gypsum or other non-carbonate minerals may establish an initial excess of dissolved calcium over CO₂ species (in molar proportions). Since calcite or aragonite precipitation removes calcium and carbonate ions in equal molar proportions (see, for example, Eugster and Hardie, 1978) evaporative concentration and precipitation from such an initial composition can result in low alkalinity and high calcium concentrations in a relatively concentrated wetland environment. Cretaceous-aged sandstone and shale (underlying the thin till at the Jarina site) may provide a source of soluble gypsum.

It appears that the low-alkalinity subset of this class (subsequently treated as a distinct grouping (Apfelbeck, in preparation)) arrive at this condition through different processes. In the apparent groundwater-recharge sites, position in the groundwater flow system probably prevents accumulation of alkalinity along with other solutes. In the Jarina site, evaporative concentration along an initially high-calcium pathway may result in accumulation of calcium at the expense of alkalinity in solution, as carbonate minerals precipitate.

Other High-Calcium Sites

The unique character of the water chemistry at the Jarina WPA (WET30) among "class 5" sites, and its apparent biological similarity to considerably more dilute sites, raises the question of what influence proportionately high calcium concentrations and/or proportionately low alkalinities (controlled by carbonate solubilities) may have on wetland biota. Some further examination of the water-column chemistry may show which other sites, if any, exhibit this type of major-ion distribution. This may help show sites in other classes where biological characteristics similar to those of the Jarina wetland might be expected.

Figure 32 simply shows calcium concentrations as a function of specific conductance. At the time of sampling, few of the wetlands maintained calcium concentrations in excess of 100 mg/l. In addition to Jarina, these include five of the more highly saline sites, Warm Springs Pond #1 and Long Lake. The figure also highlights the strongly calcium-depleted sites. With the exception of Black Coulee, all of the notably low-calcium sites are either very dilute, are included in the highly saline closed-basin class, or are included in what is referred to here as "class 5".

Figure 32 also shows alkalinity (neglecting hydroxide) as a function of specific conductance. The high-Ca sites are notable for being proportionately low-alkalinity, while the calcium-depleted sites follow the high-alkalinity margin of the alkalinity-specific conductance field. This suggests the important influence

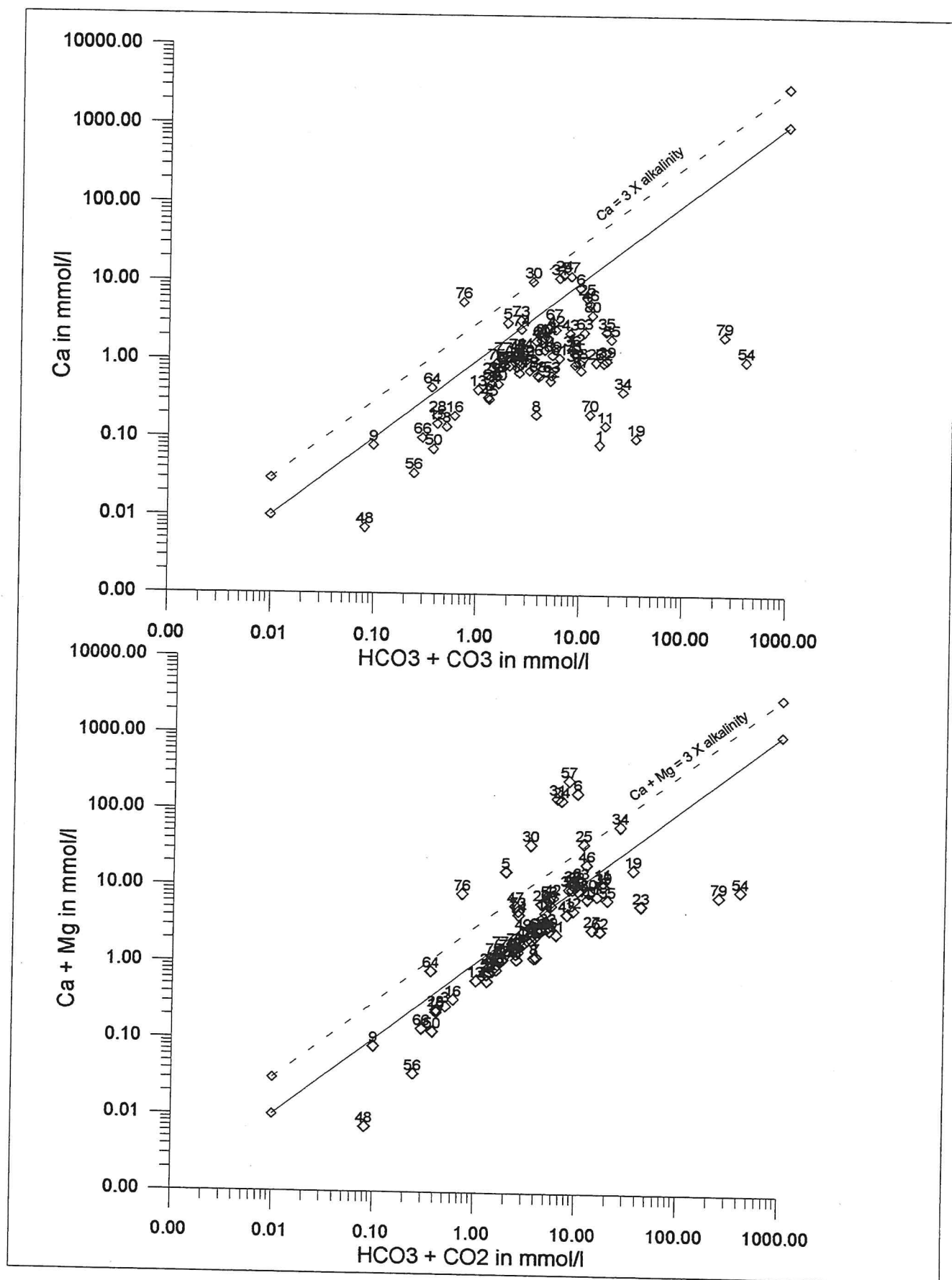


Figure 33. Calcium and calcium plus magnesium in mmol/l plotted against carbonate alkalinity.

of calcium carbonate solubility on wetland water composition among these sites. Except in the unusual case where initial molar concentrations of calcium and carbonate are equal, precipitation of calcium carbonate during evaporative concentration leads to antipathetic changes in calcium and carbonate alkalinity, and ultimately to the depletion of one or the other (Hardie and Eugster, 1970).

Benton Lake and the Mallard Pond sample (which appears to be influenced by unequilibrated groundwater discharge - see Appendix A) are the only sites in the low-alkalinity region which are not also notably high in dissolved calcium; Long Lake is the only one of the highest 10% of calcium concentrations which is not among the notably low alkalinity sites.

Figure 33 shows the sum of the CO₂ species in millimoles/liter as a function of calcium plus magnesium and calcium alone. The straight line marks a molar ratio of 1 (stoichiometry of (Ca,Mg)CO₃). The calcium-only plot suggests that the molar concentrations of calcium needed to maintain relatively low alkalinities through carbonate precipitation at moderate to high salinities exists in basically the same limited number of sites highlighted by the plots of CO₂ species and calcium concentrations. Most wetlands sampled have compositions encouraging the accumulation of water column alkalinity during calcium carbonate precipitation; of the "oligosaline" sites, only Benton Lake (WET06) and Long Lake (WET47) join the Jarina site on the low-carbonate side of the "chemical divide" of Hardie and Eugster (1970). During evaporative concentration, these sites may avoid increasing alkalinity through the depletion effects of carbonate precipitation.

The plot of Ca+Mg is less informative; kinetic constraints on magnesium carbonate formation (Kelts and Hsu, 1978; Donovan, 1992) typically allow high degrees of theoretical supersaturation with Mg carbonates, making magnesium carbonate solubility a less probable constraint on alkalinity. (This is shown by the high concentrations of magnesium and alkalinity in Ca-depleted sites such as Alkali Lake).

Generally, the sites with high alkalinities and depleted calcium concentrations include those where ground-water dominated inflow is strongly suggested by the geologic setting or by the water budget limitations of small drainage basin to wetland area ratios, or both. Generally, the less common moderate to highly saline sites with proportionately low alkalinities are in settings where geology and/or topography are probably unfavorable for ground-water discharge, or where large catchments suggest that ground-water inflow is small relative to surface runoff.

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Appendix A, part 1

Geologic, Geomorphic and Chemical Characteristics of Wetlands Selected for Use in Biocriteria Development by the Montana Department of Environmental Quality

by

Mark D. Shapley
Montana Natural Heritage Program
1515 East 6th Avenue
Helena, MT 59620

for the

Montana Department of Environmental Quality
Water Quality Division

December, 1995

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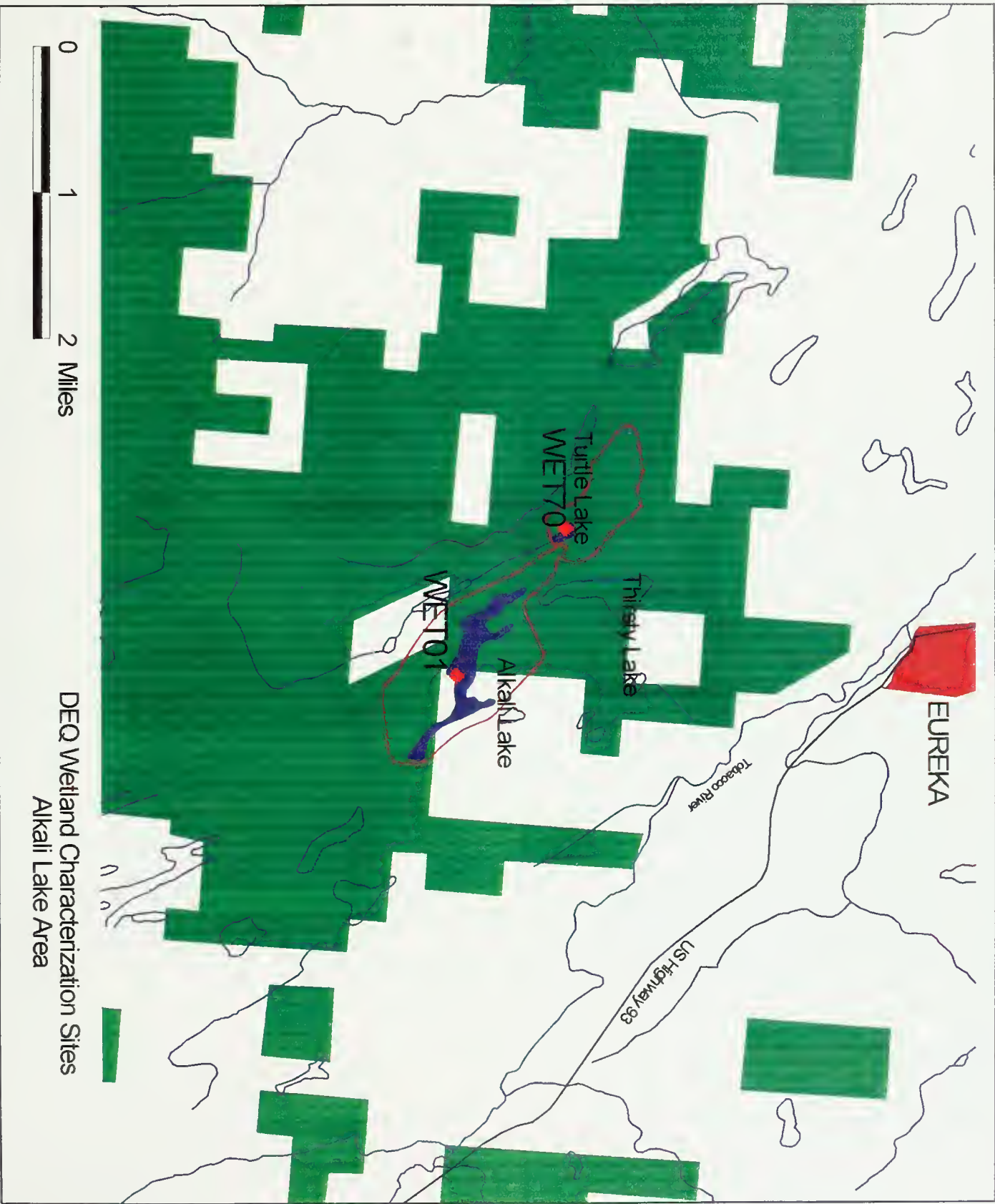


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Appendix A

Data Summaries and Maps of the
DEQ Wetland Characterization Sites

Part 1, Sites WET01 - WET40



Wetland: ALKALI LAKE

Site Code: WET01

7.5 Minute Quad: EUREKA SOUTH

Lat: 48 50 5

Long: 115 2 30

Mean Annual Precipitation in Inches: 17.00

Mean Annual Potential Evaporation (Penman) in Inches: 30.00

'Net Precipitation' in Inches: -13.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 100 acres

Area of contributing drainage basin: 560 acres

Mapped elevation of wetland surface: 2982 ft

Maximum elevation within drainage basin: 3210 ft

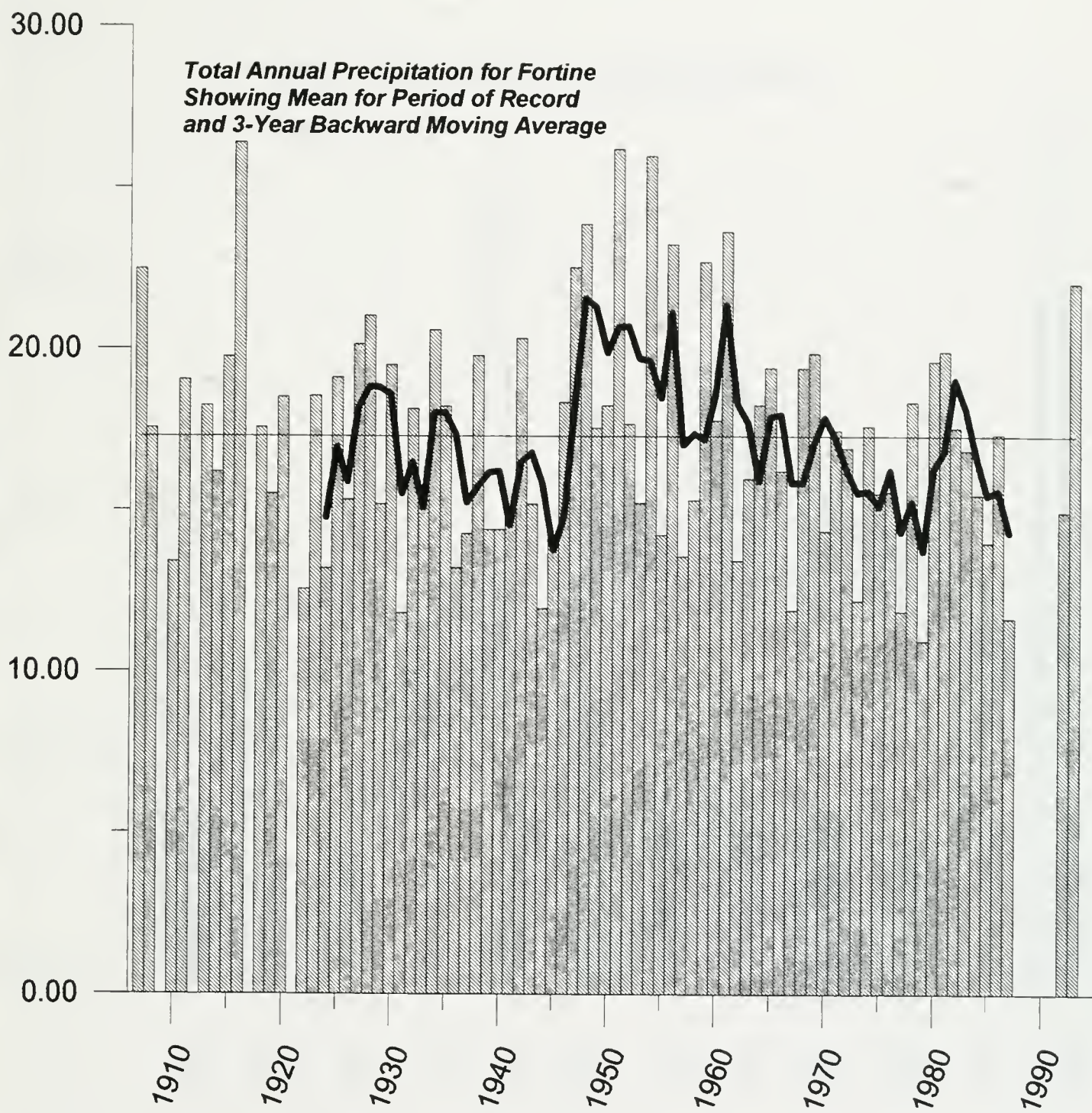
Net relief of contributing basin: 228 ft

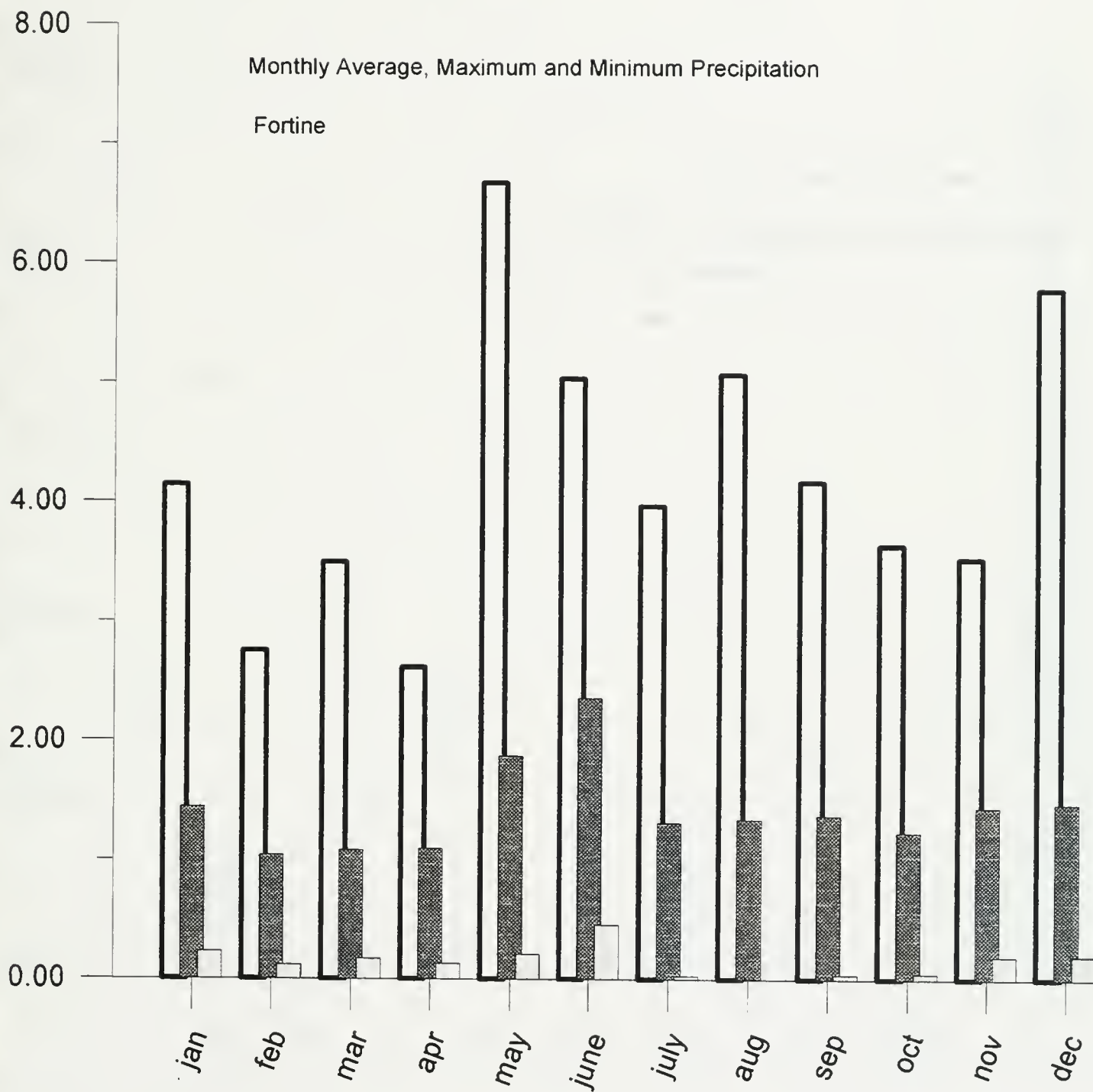
COE Hydrogeomorphic class: FRINGE

Primary surficial geologic unit 112TILL

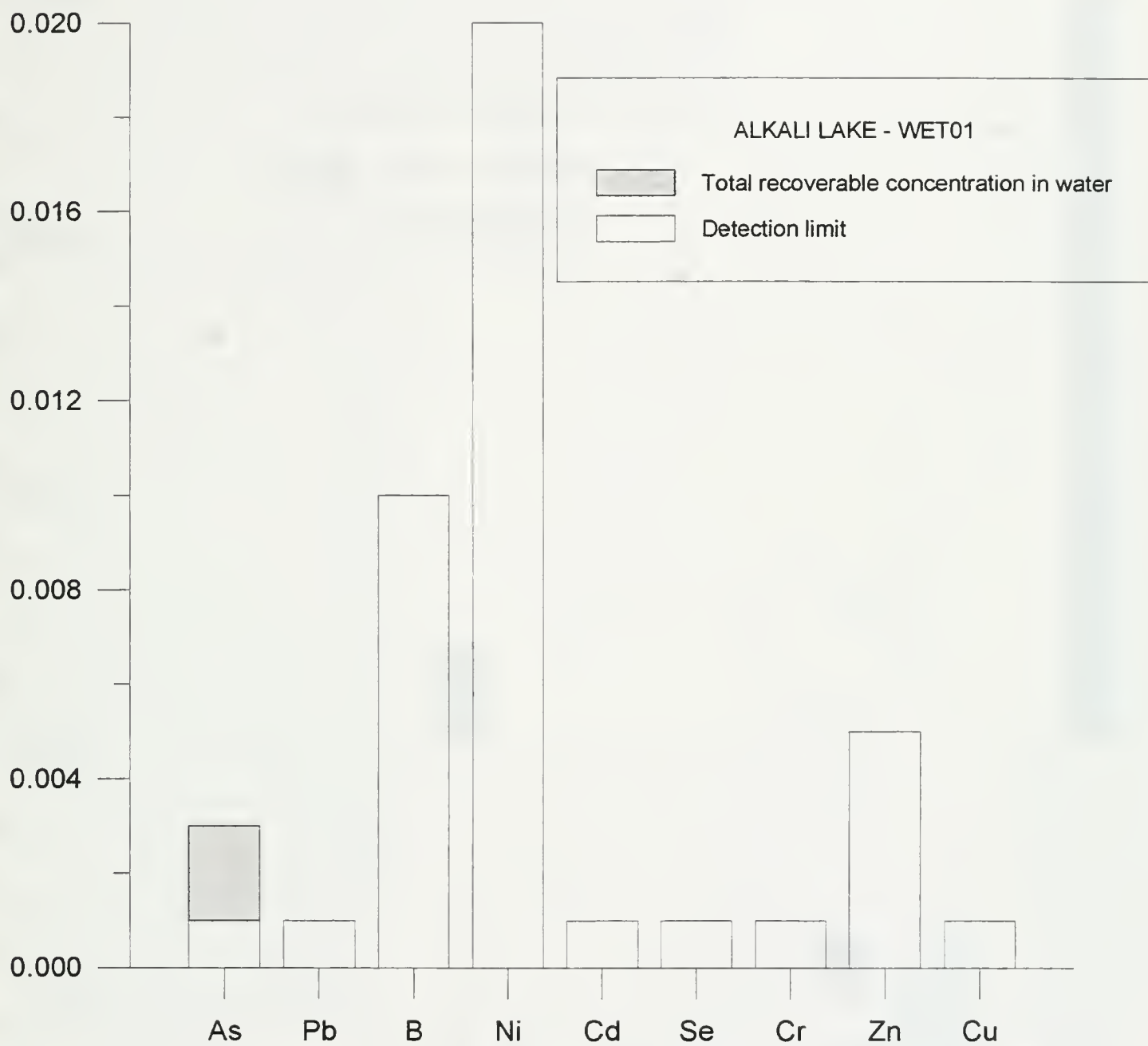
Primary bedrock geologic unit 400BELT

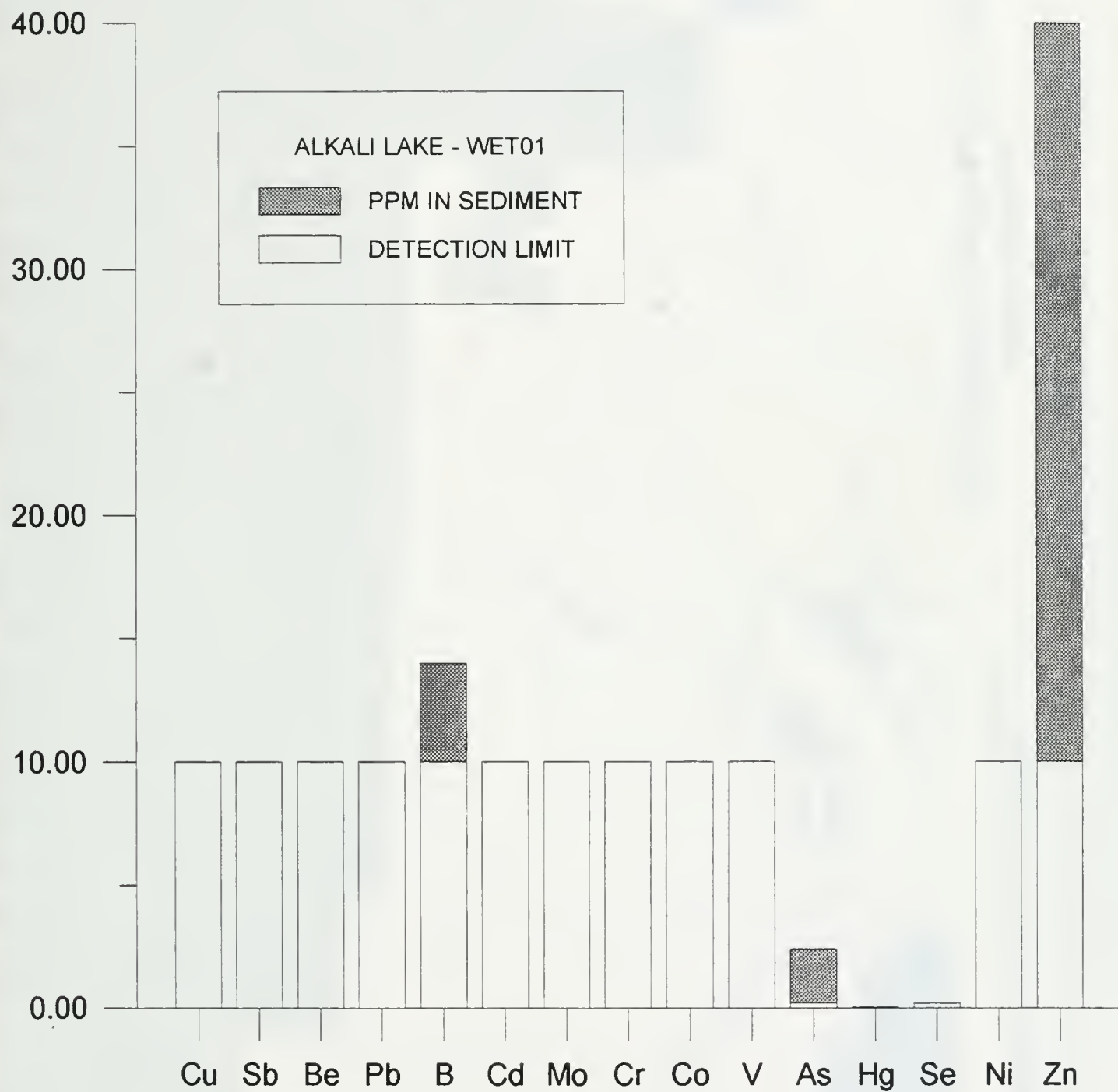
Annual Precipitation in Inches

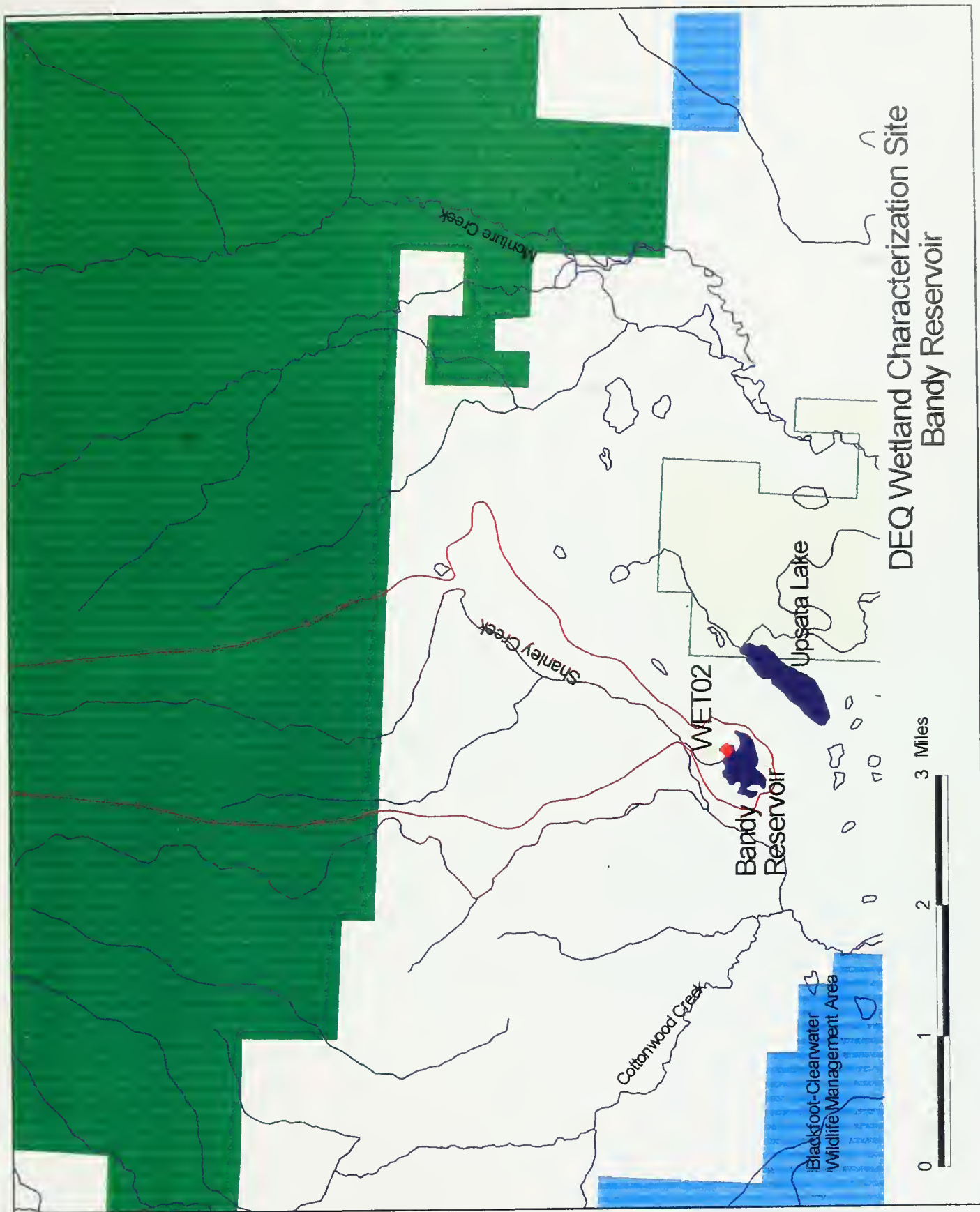




Concentrations in Milligrams per liter







Wetland: BANDY RESERVOIR

Site Code: WET02

7.5 Minute Quad: OVANDO

Lat: 47 5 2

Long: 113 13 58

Mean Annual Precipitation in Inches:	17.00
Mean Annual Potential Evaporation (Penman) in Inches:	32.00
'Net Precipitation' in Inches:	-15.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

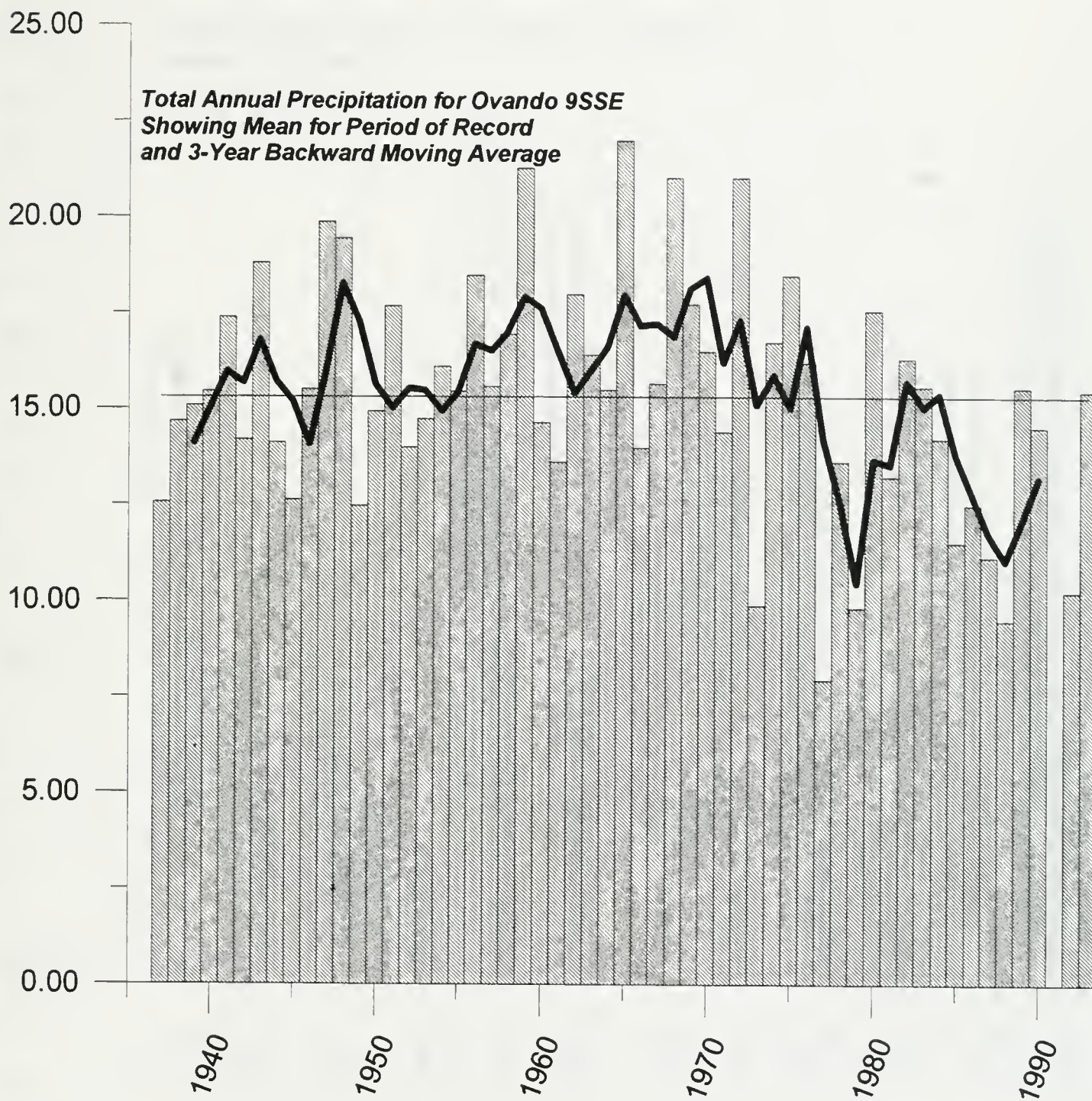
Site is artificially impounded.

Site has significant water imports.

Mapped area of wetland:	57 acres
Area of contributing drainage basin:	5900 acres
Mapped elevation of wetland surface:	4210 ft
Maximum elevation within drainage basin:	4335 ft
Net relief of contributing basin:	125 ft

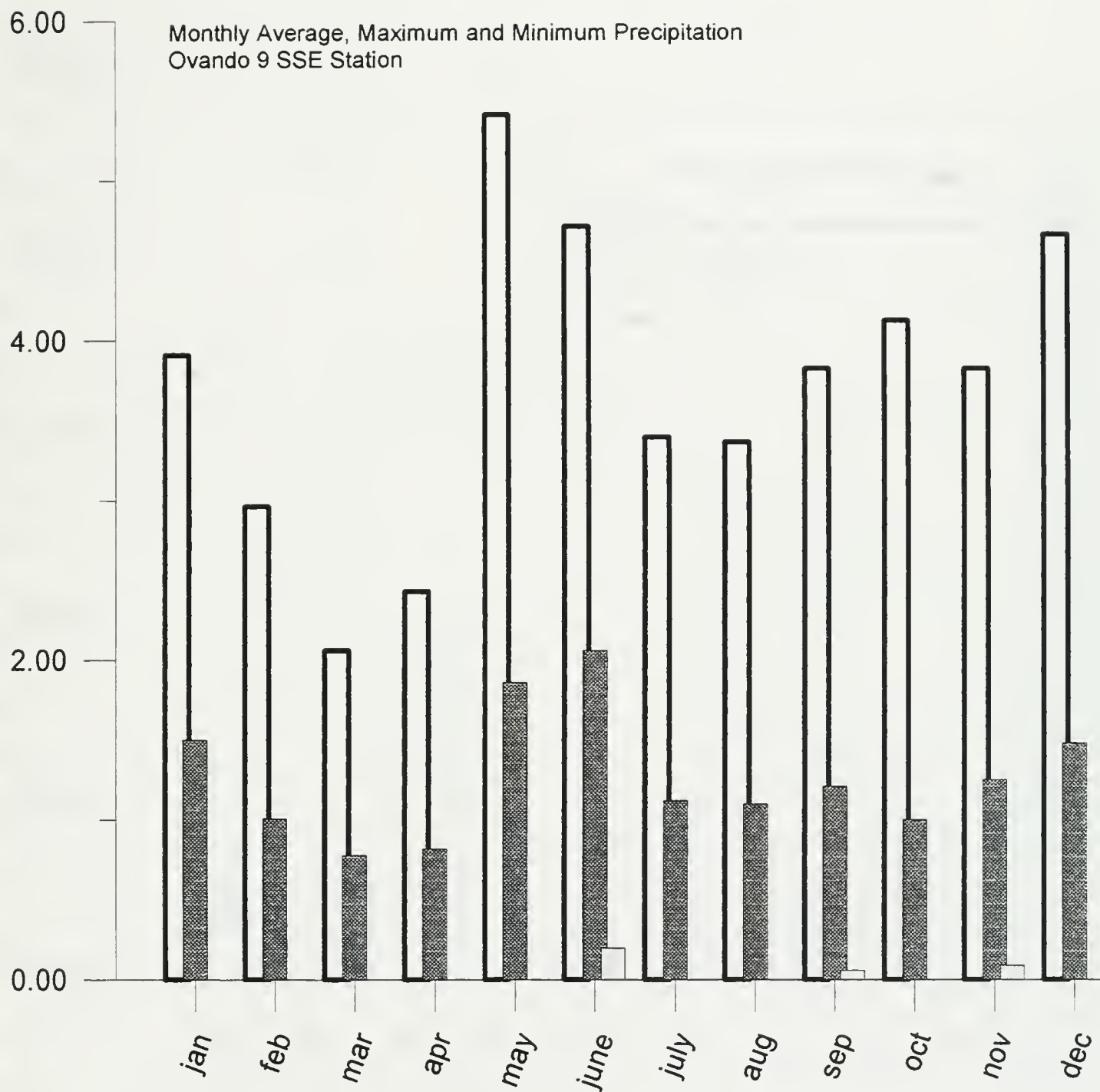
COE Hydrogeomorphic class:	DEPRESSIONAL
Primary surficial geologic unit	112TILL
Primary bedrock geologic unit	120SDMS

Annual Precipitation in Inches

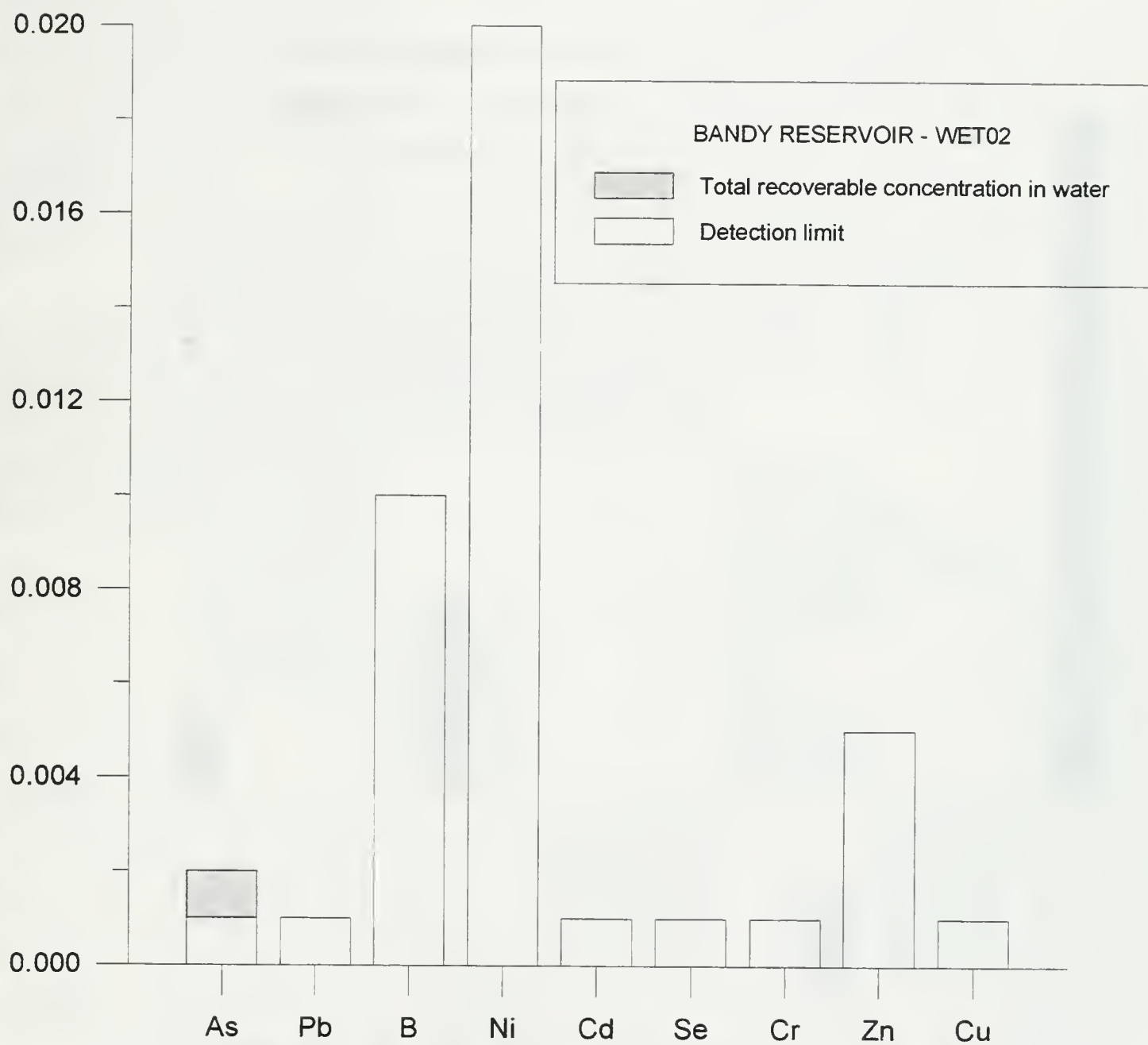


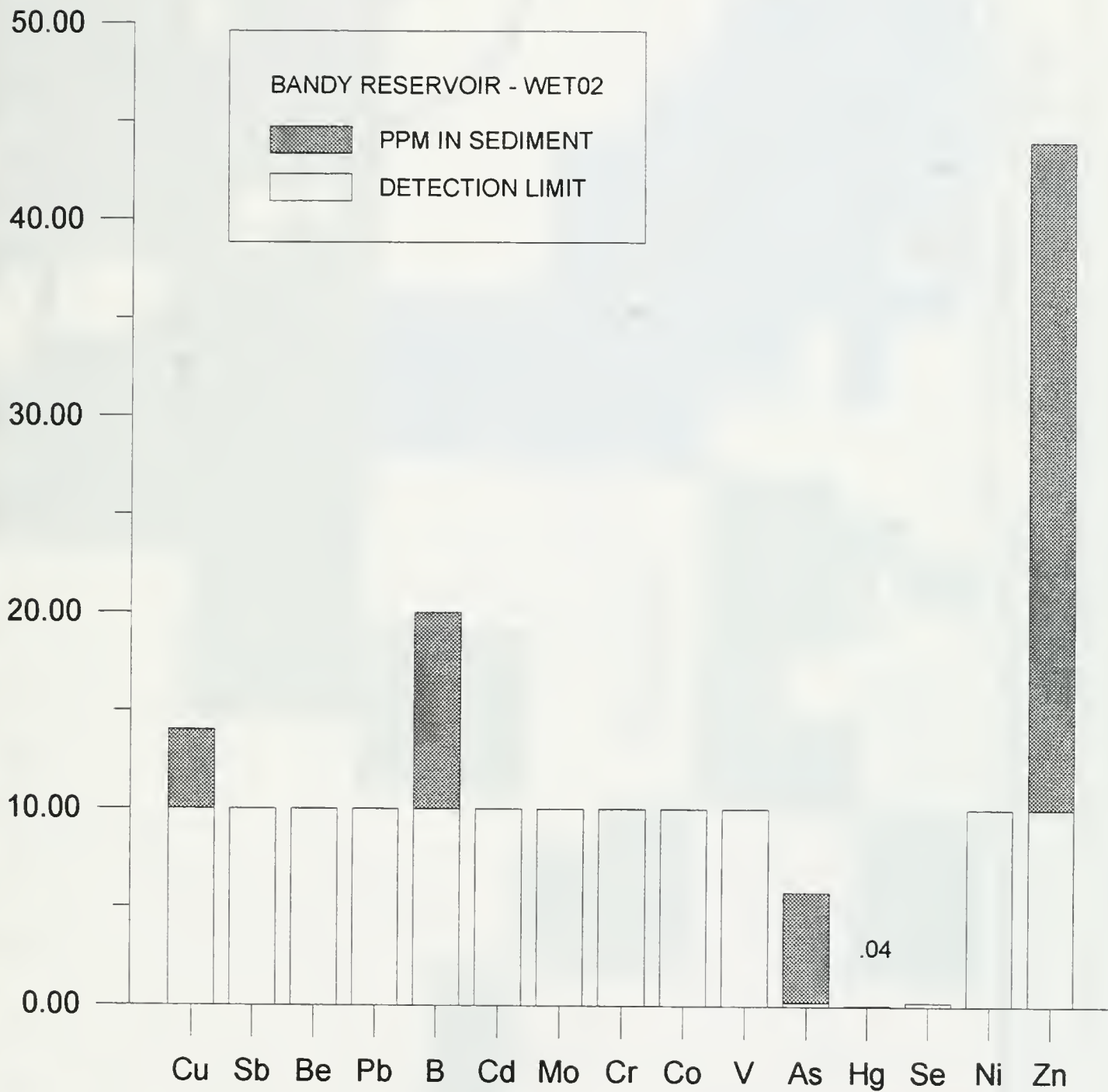
Inches Precipitation

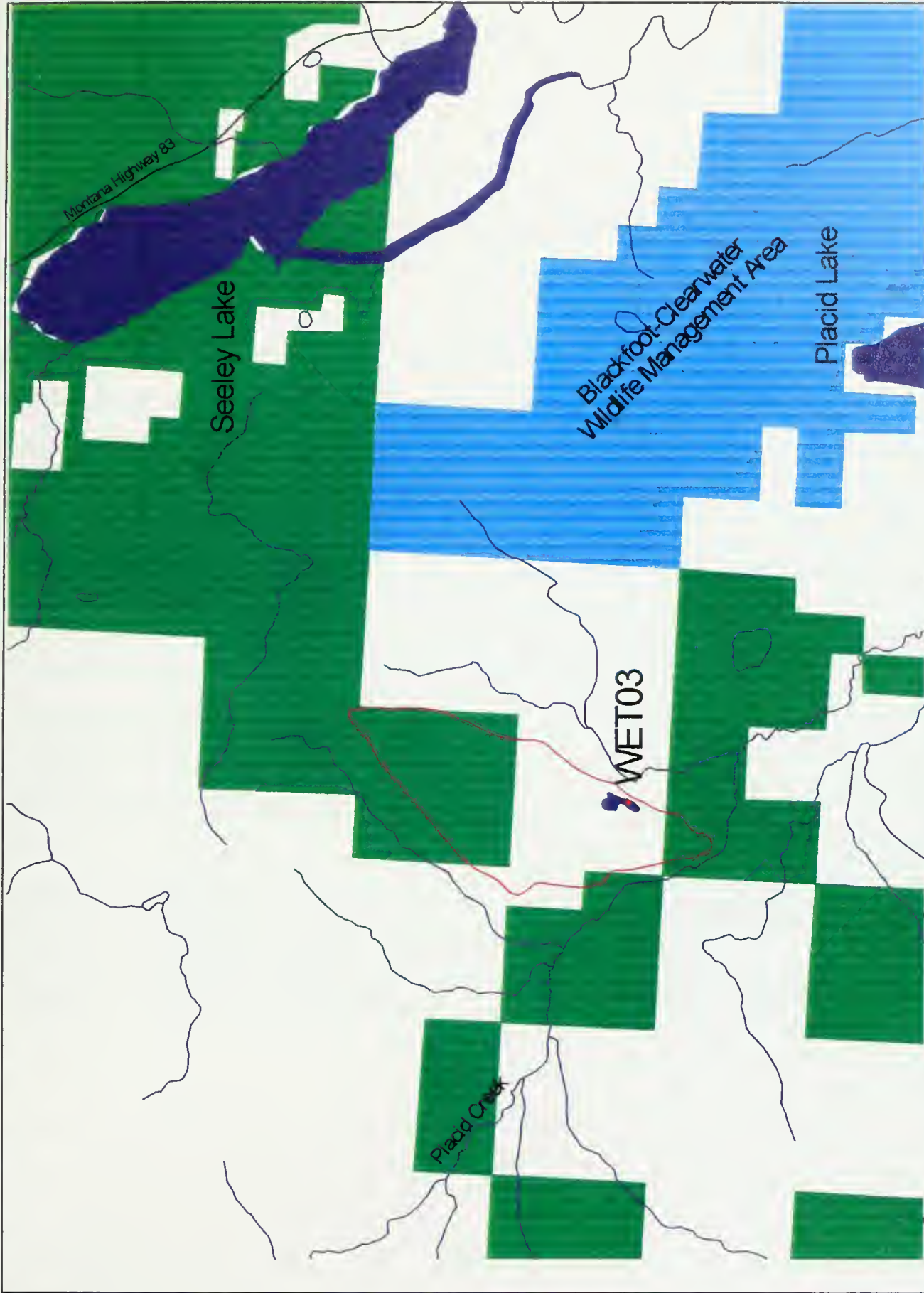
Monthly Average, Maximum and Minimum Precipitation
Ovando 9 SSE Station



Concentrations in Milligrams per liter







DEQ Wetland Characterization Site
Beaver Creek

Wetland: BEAVER CREEK WETLAND

Site Code: WET03

7.5 Minute Quad: SEELEY LAKE WEST

Lat: 47 9 15

Long: 113 35 20

Mean Annual Precipitation in Inches: 25.00

Mean Annual Potential Evaporation (Penman) in Inches: 31.00

'Net Precipitation' in Inches: -6.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 10 acres

Area of contributing drainage basin: 930 acres

Mapped elevation of wetland surface: 4275 ft

Maximum elevation within drainage basin: 4465 ft

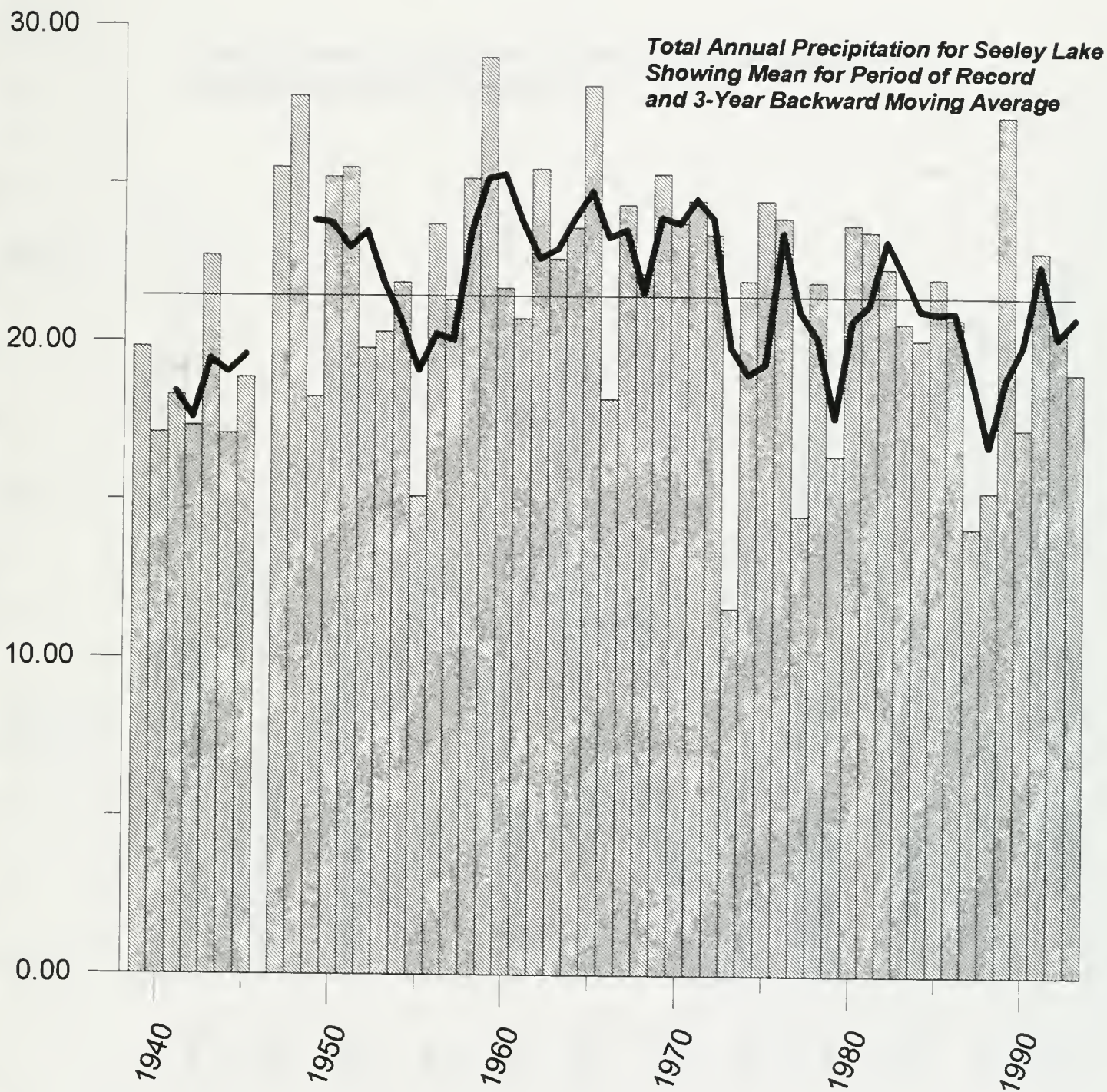
Net relief of contributing basin: 190 ft

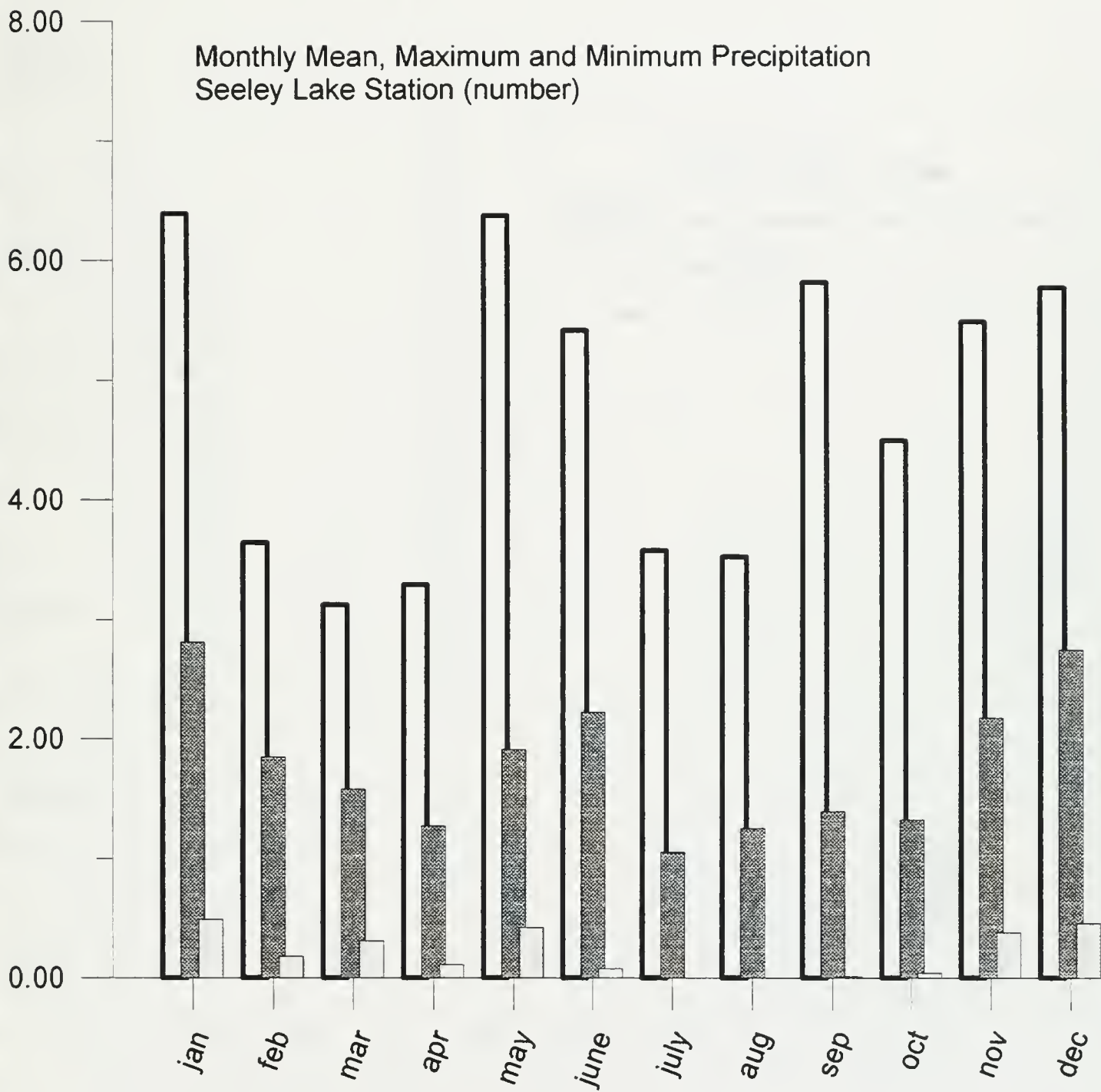
COE Hydrogeomorphic class: DEPRESSIONAL

Primary surficial geologic unit 112DRFT

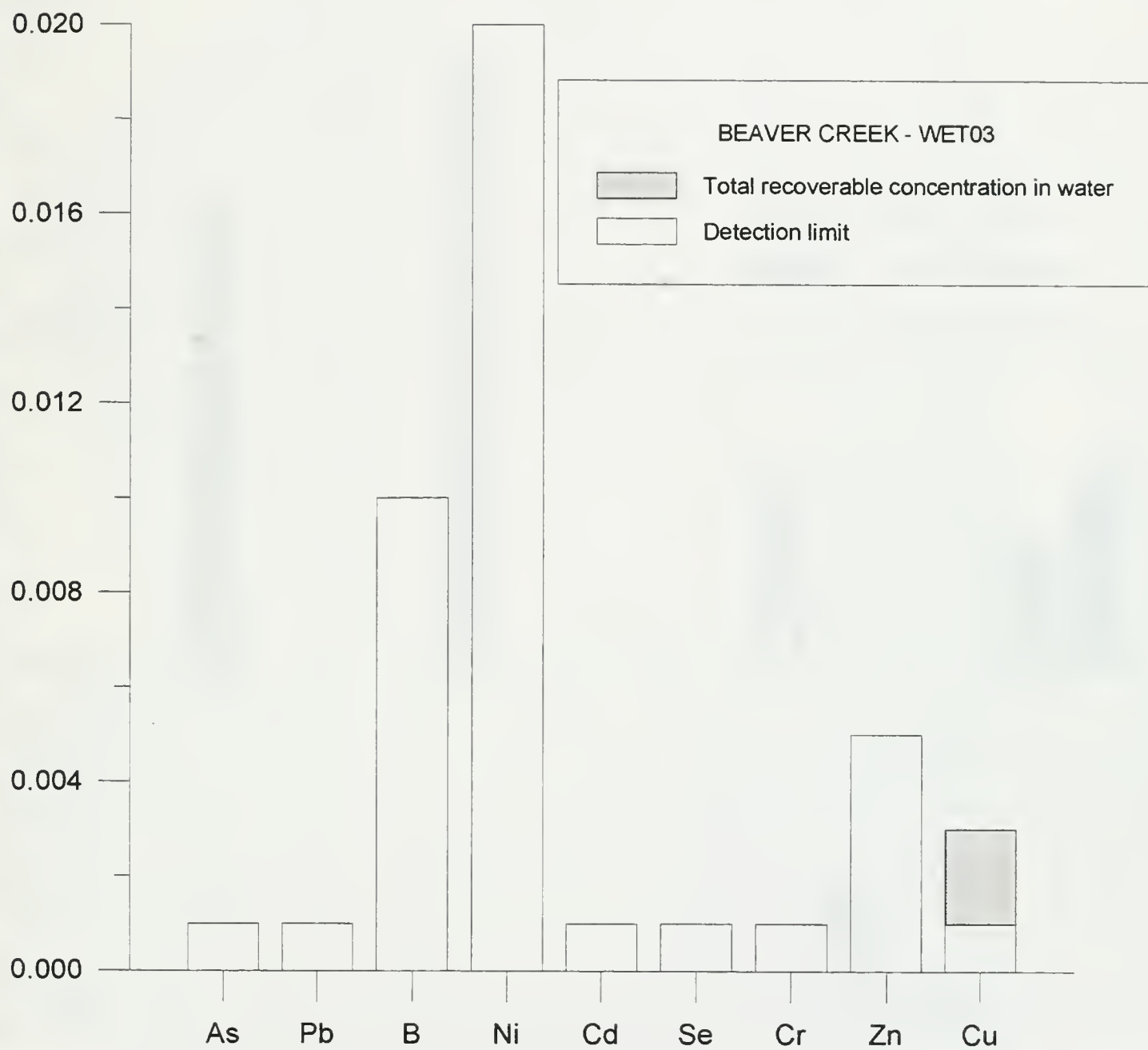
Primary bedrock geologic unit 400BELT

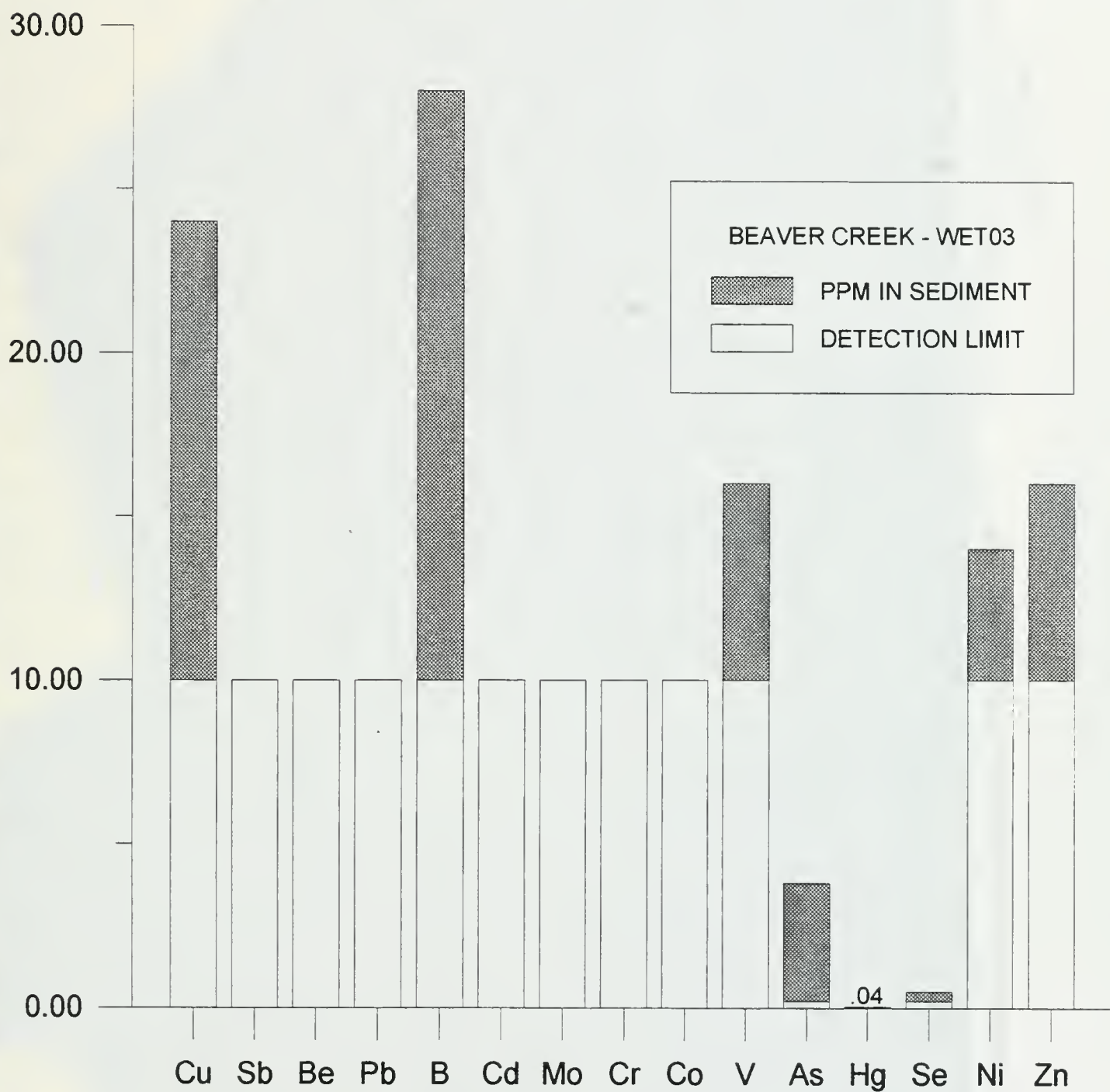
Annual Precipitation in Inches





Concentrations in Milligrams per liter







DEQ Wetland Characterization Site
Bent Flat Fen

Wetland: BENT FLAT FEN PROPOSED RNA

Site Code: WET04

7.5 Minute Quad: SPOTTED BEAR MOUNTAIN

Lat: 47 56 45

Long: 113 26 55

Mean Annual Precipitation in Inches: 25.00

Mean Annual Potential Evaporation (Penman) in Inches: 29.00

'Net Precipitation' in Inches: -4.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 12 acres

Area of contributing drainage basin: 570 acres

Mapped elevation of wetland surface: 3980 ft

Maximum elevation within drainage basin: 6004 ft

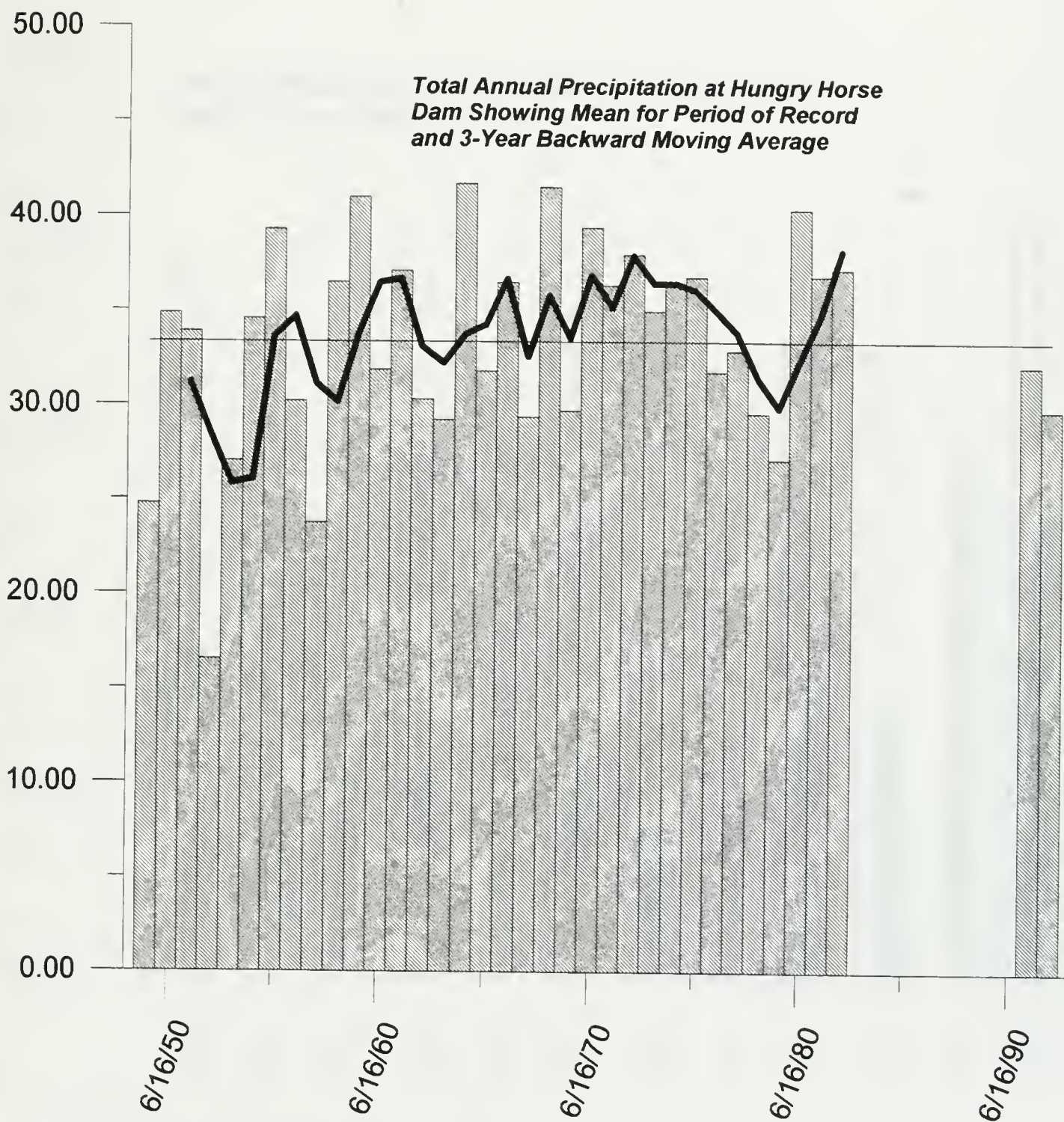
Net relief of contributing basin: 2024 ft

COE Hydrogeomorphic class: EXTENS PEAT

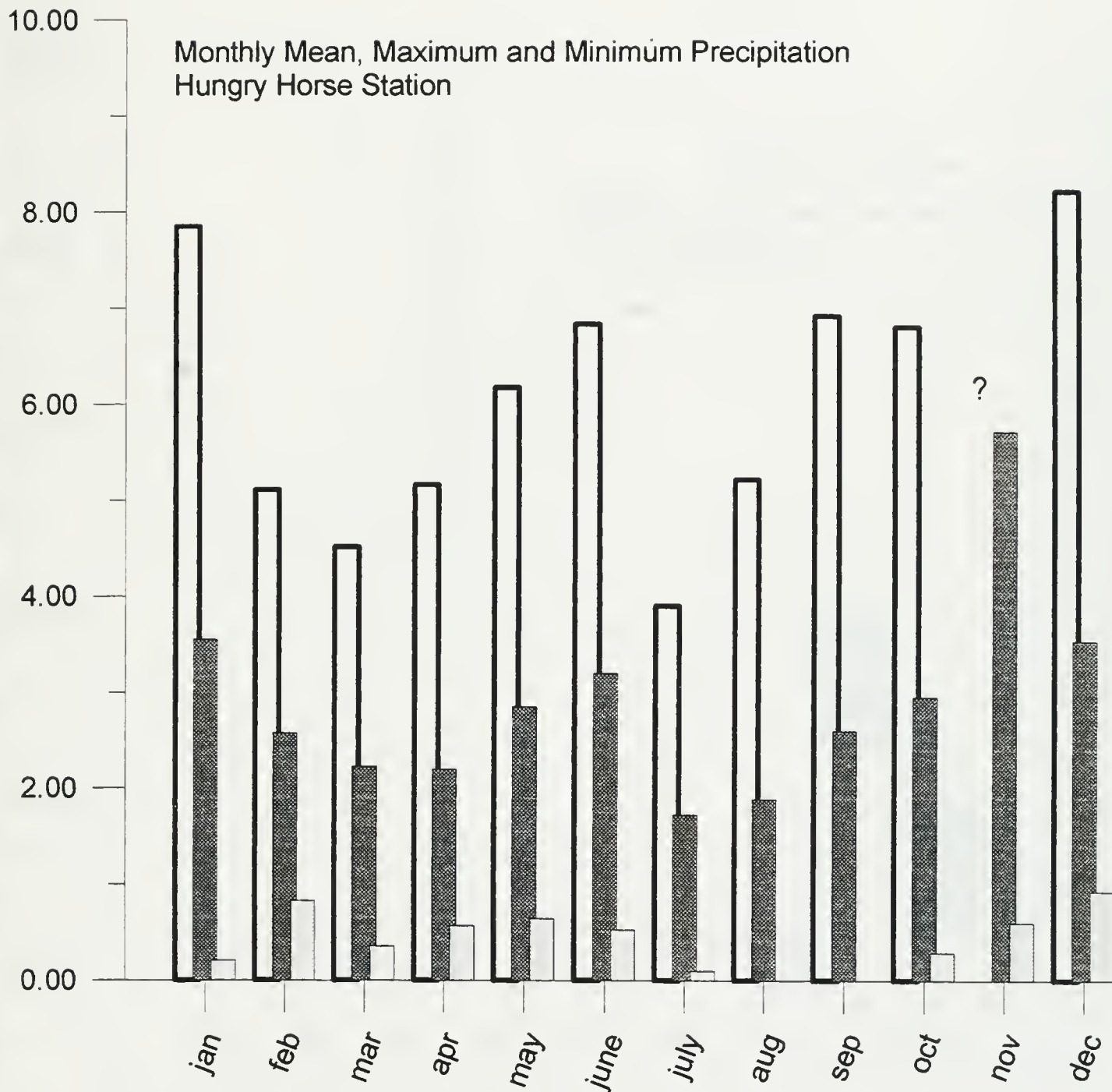
Primary surficial geologic unit 112TILL

Primary bedrock geologic unit 370CMBR

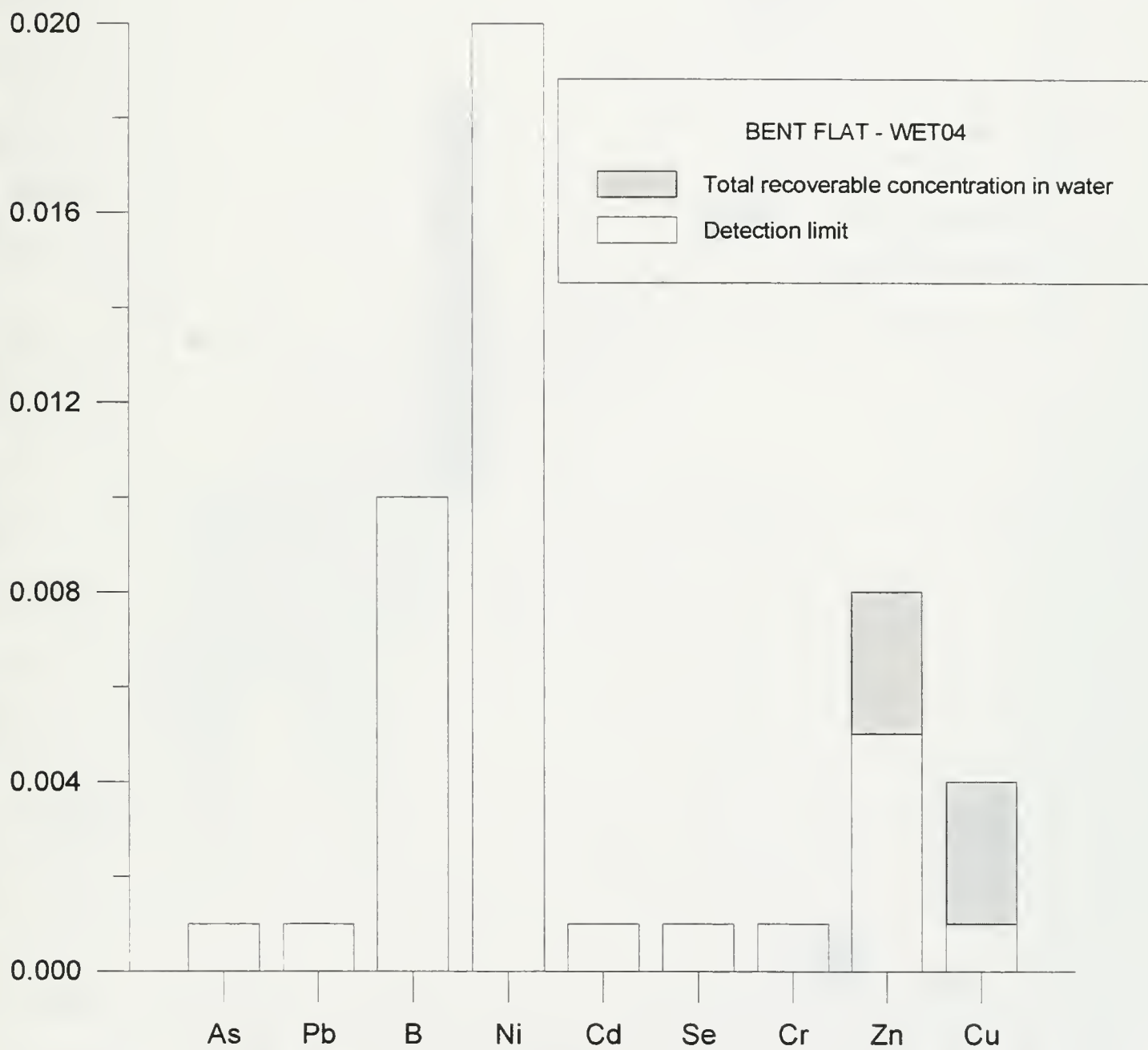
Annual Precipitation in Inches

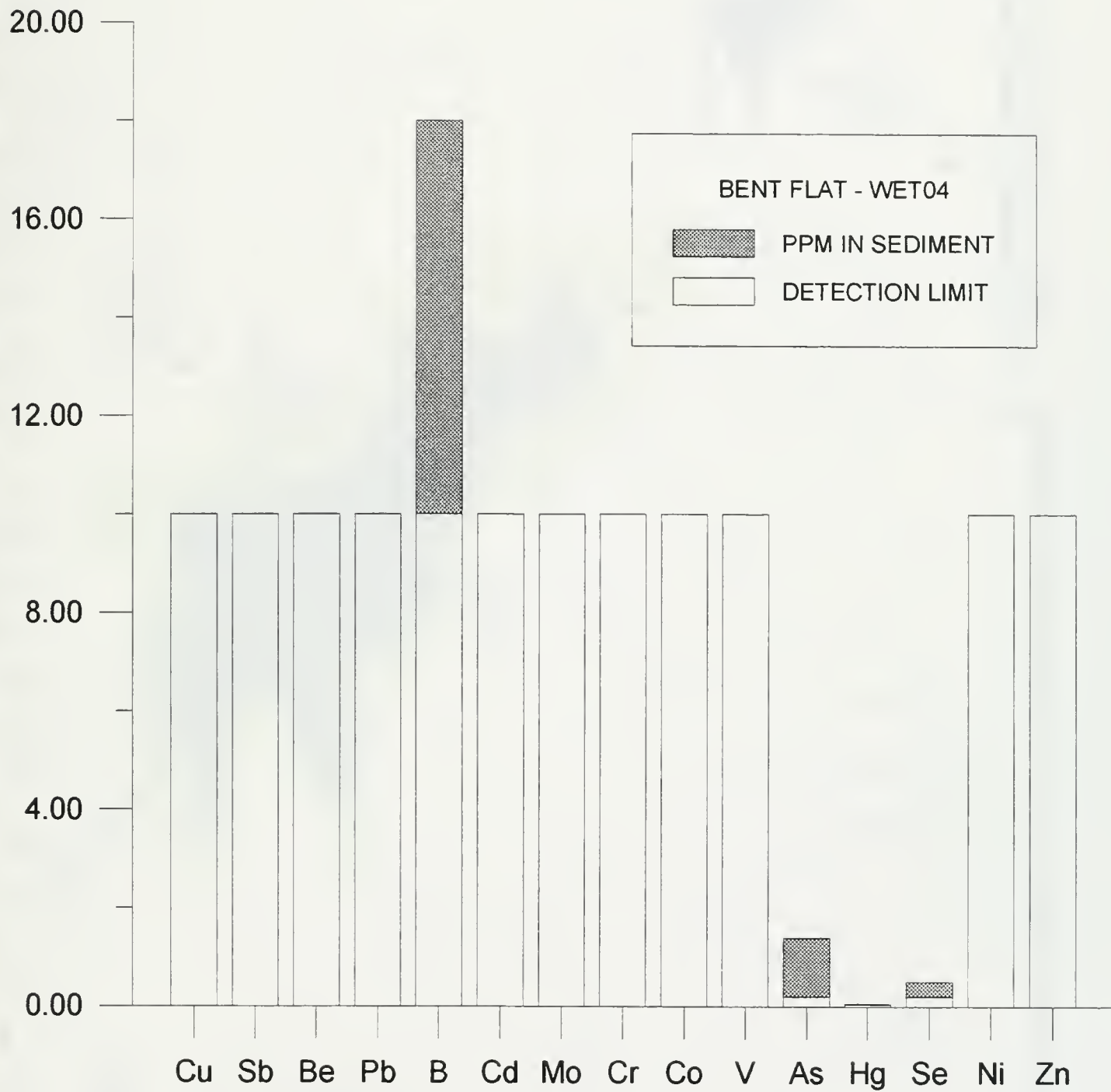


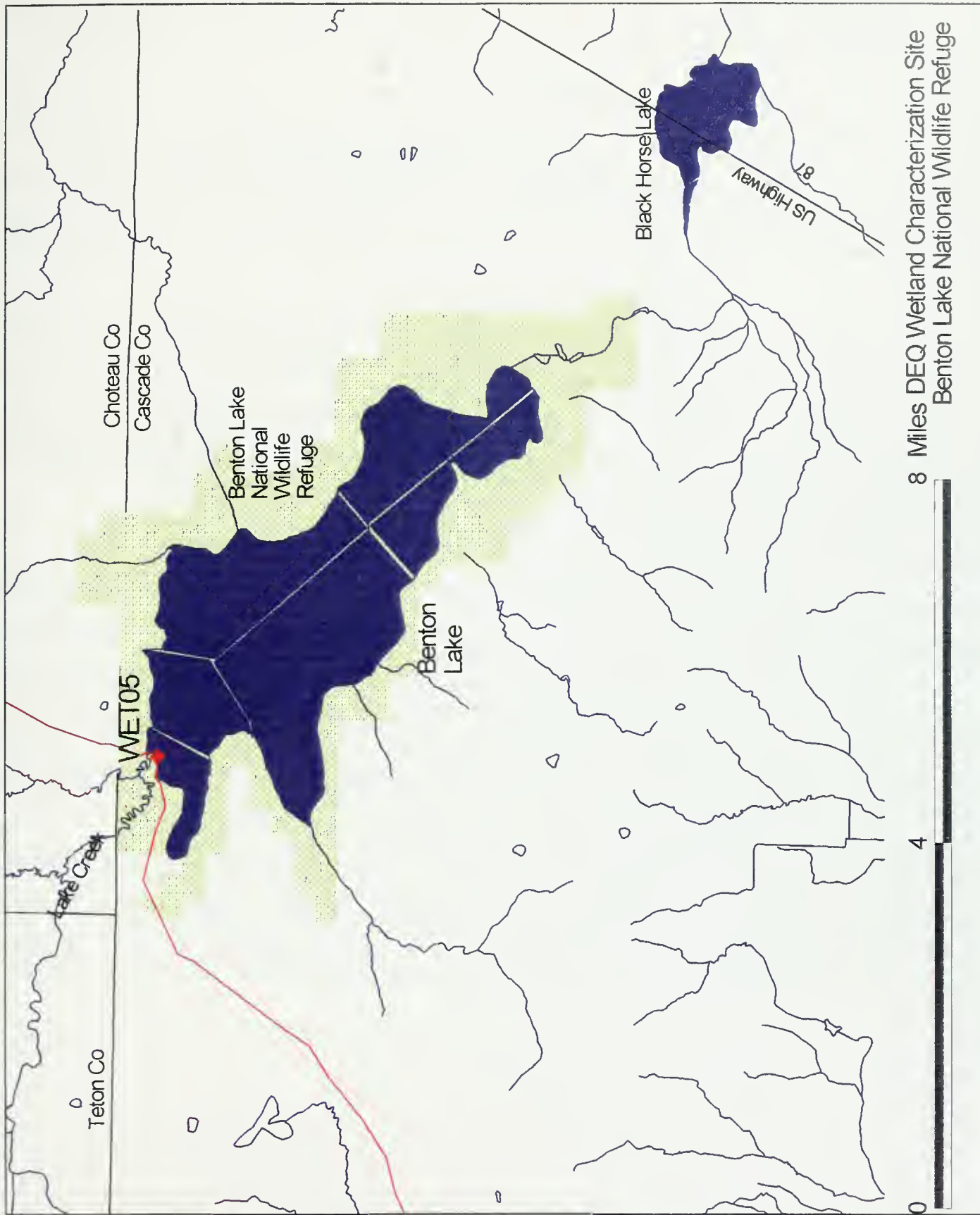
Inches Precipitation



Concentrations in Milligrams per liter







Wetland: BENTON LAKE

Site Code: WET05

7.5 Minute Quad: BENTON LAKE EAST

Lat: 47 41 45

Long: 111 22 15

Mean Annual Precipitation in Inches: 13.00

Mean Annual Potential Evaporation (Penman) in Inches: 40.00

'Net Precipitation' in Inches: -27.00

Site has a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is artificially impounded.

Site has significant water imports.

Mapped area of wetland: 5300 acres

Area of contributing drainage basin: 54040 acres

Mapped elevation of wetland surface: 3620 ft

Maximum elevation within drainage basin: 3950 ft

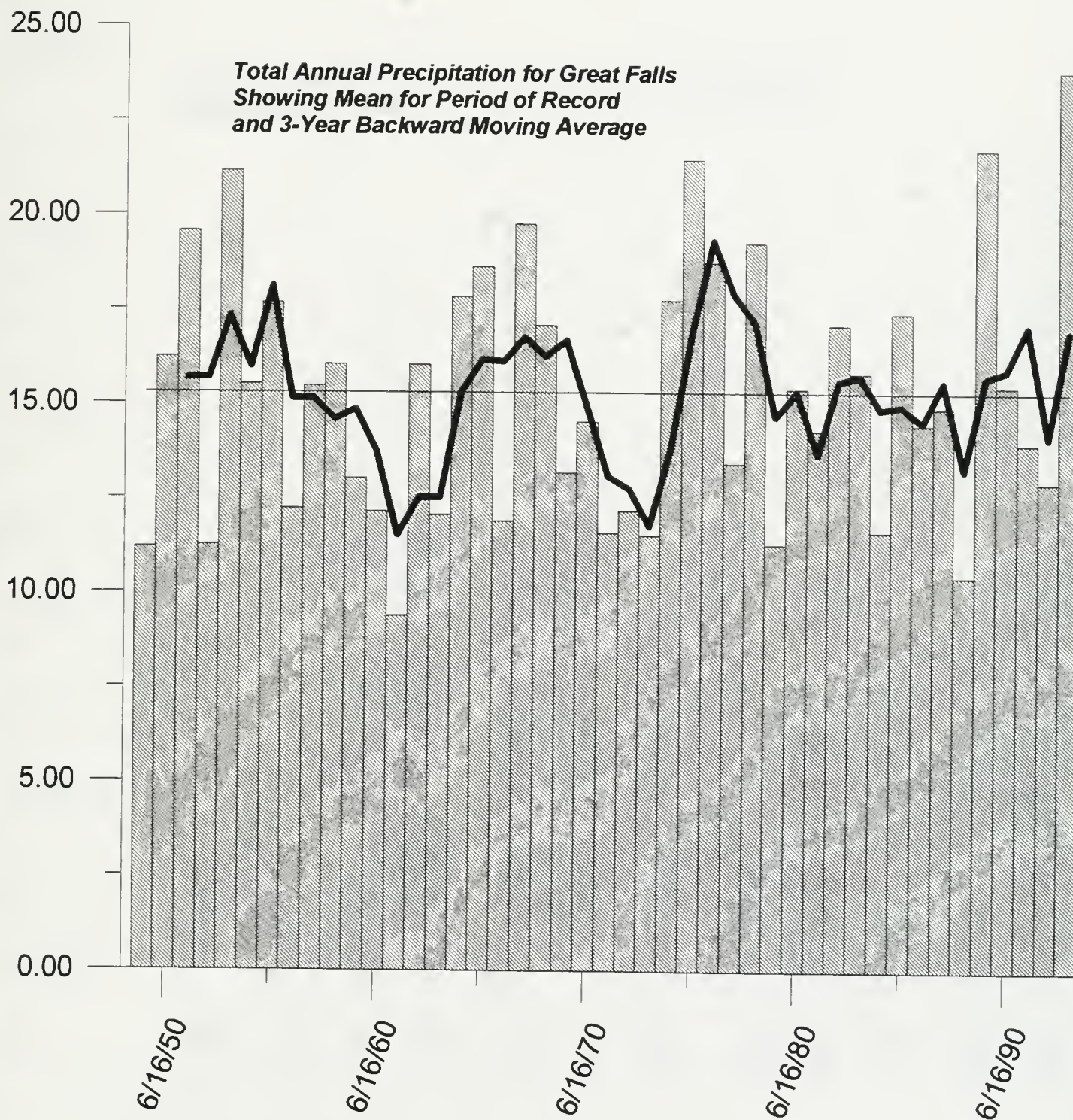
Net relief of contributing basin: 330 ft

COE Hydrogeomorphic class: FRINGE

Primary surficial geologic unit 112GLCC

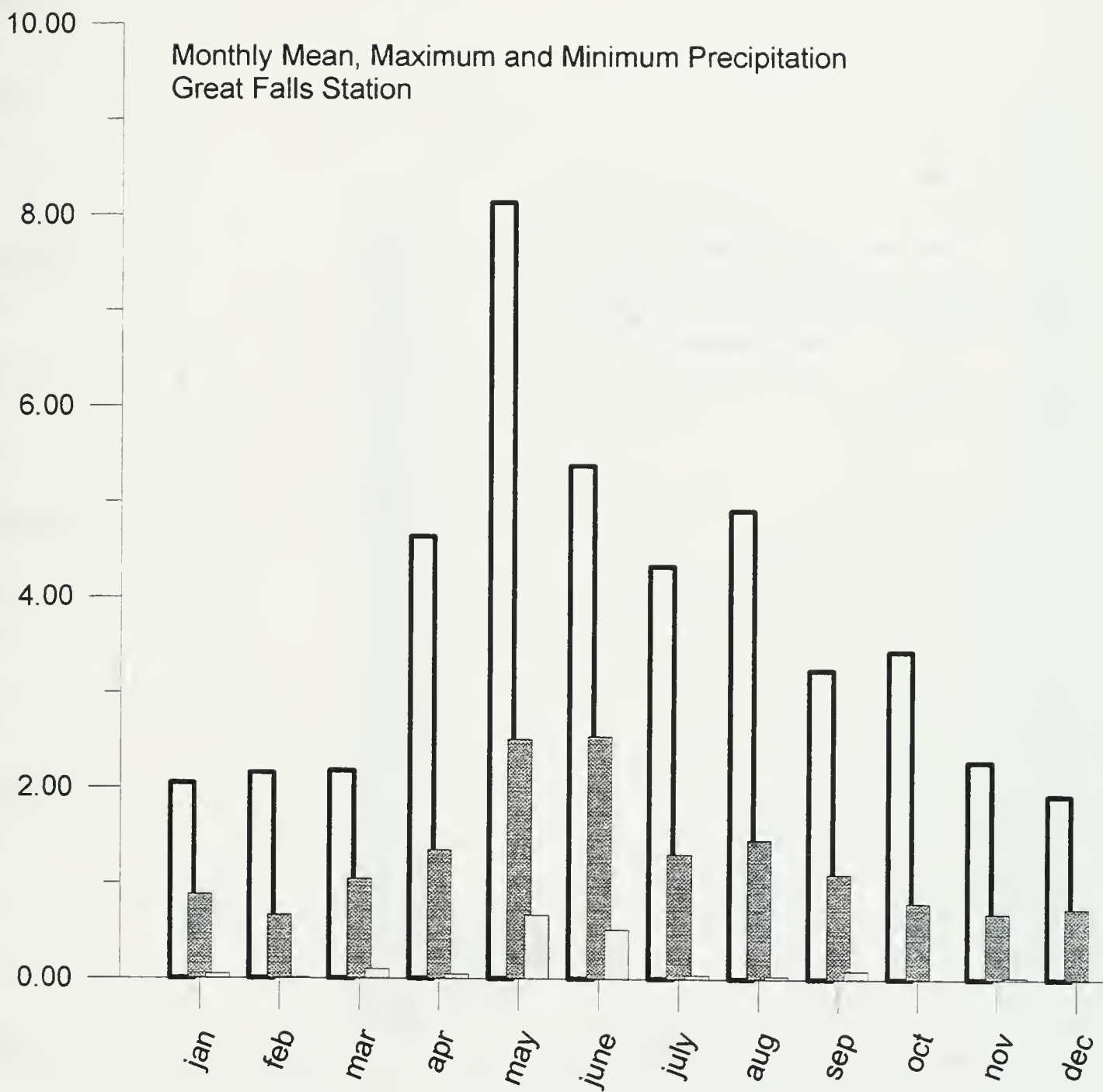
Primary bedrock geologic unit 211CLRD

Annual Precipitation in Inches

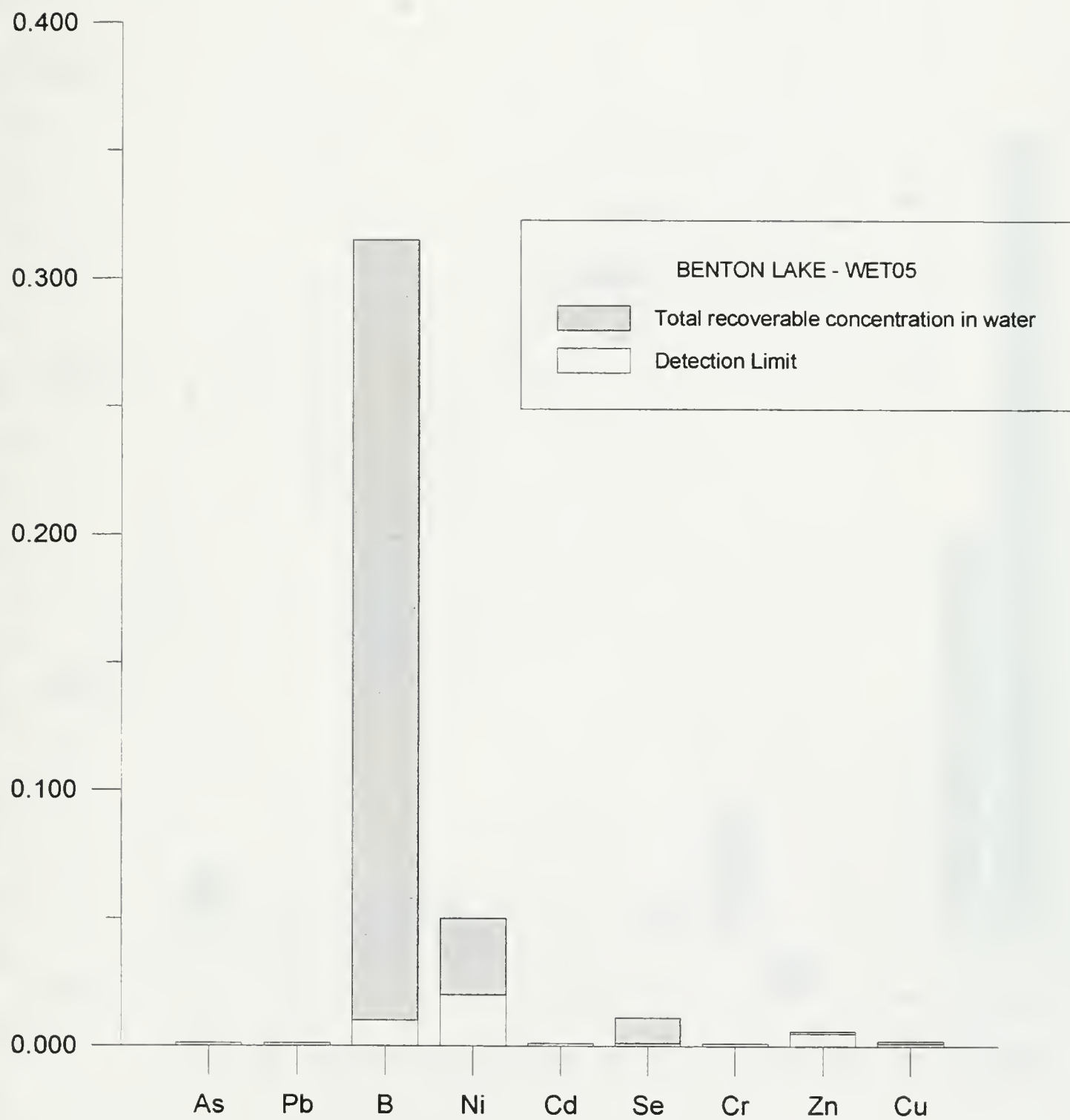


Inches Precipitation

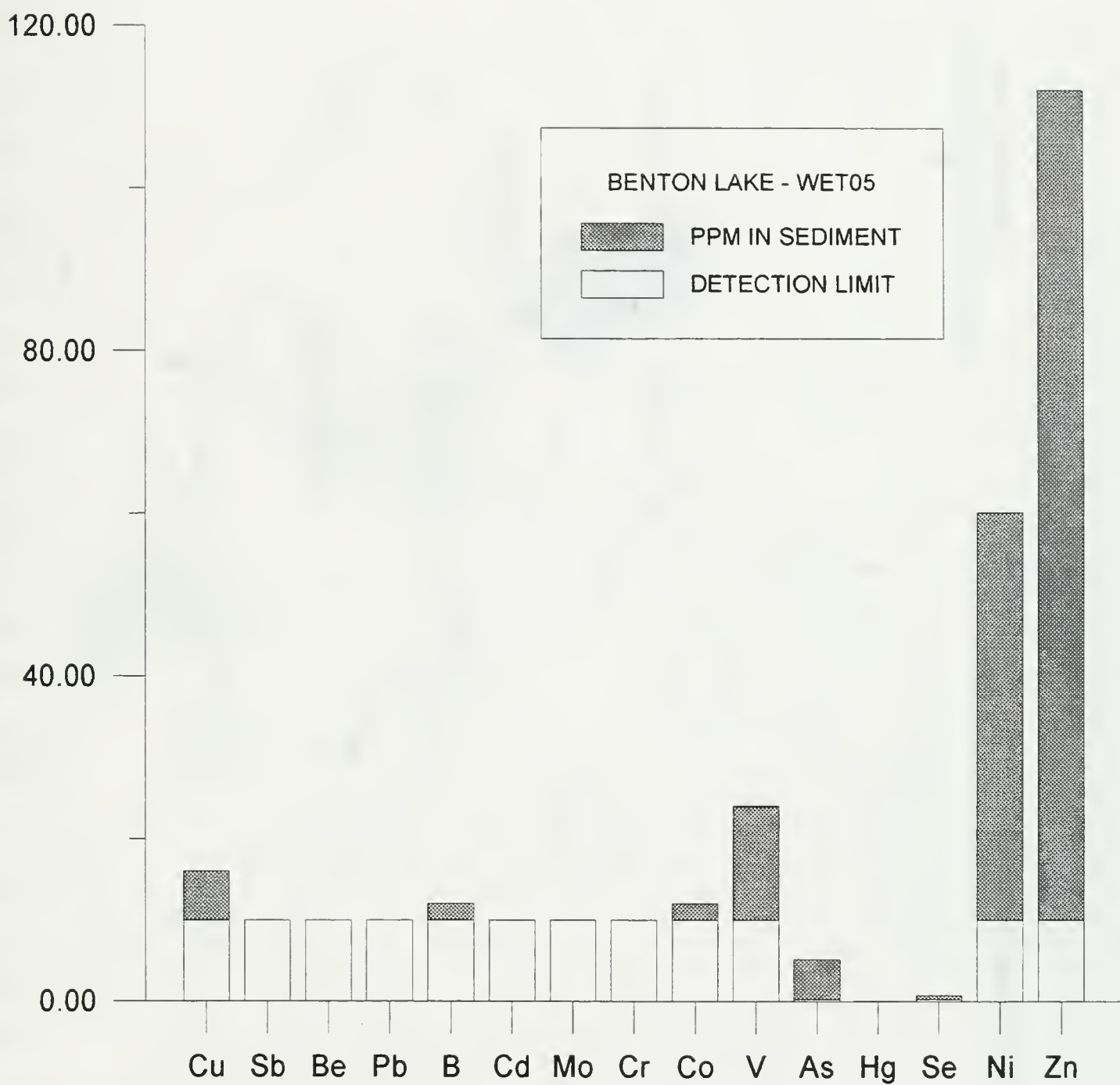
Monthly Mean, Maximum and Minimum Precipitation
Great Falls Station

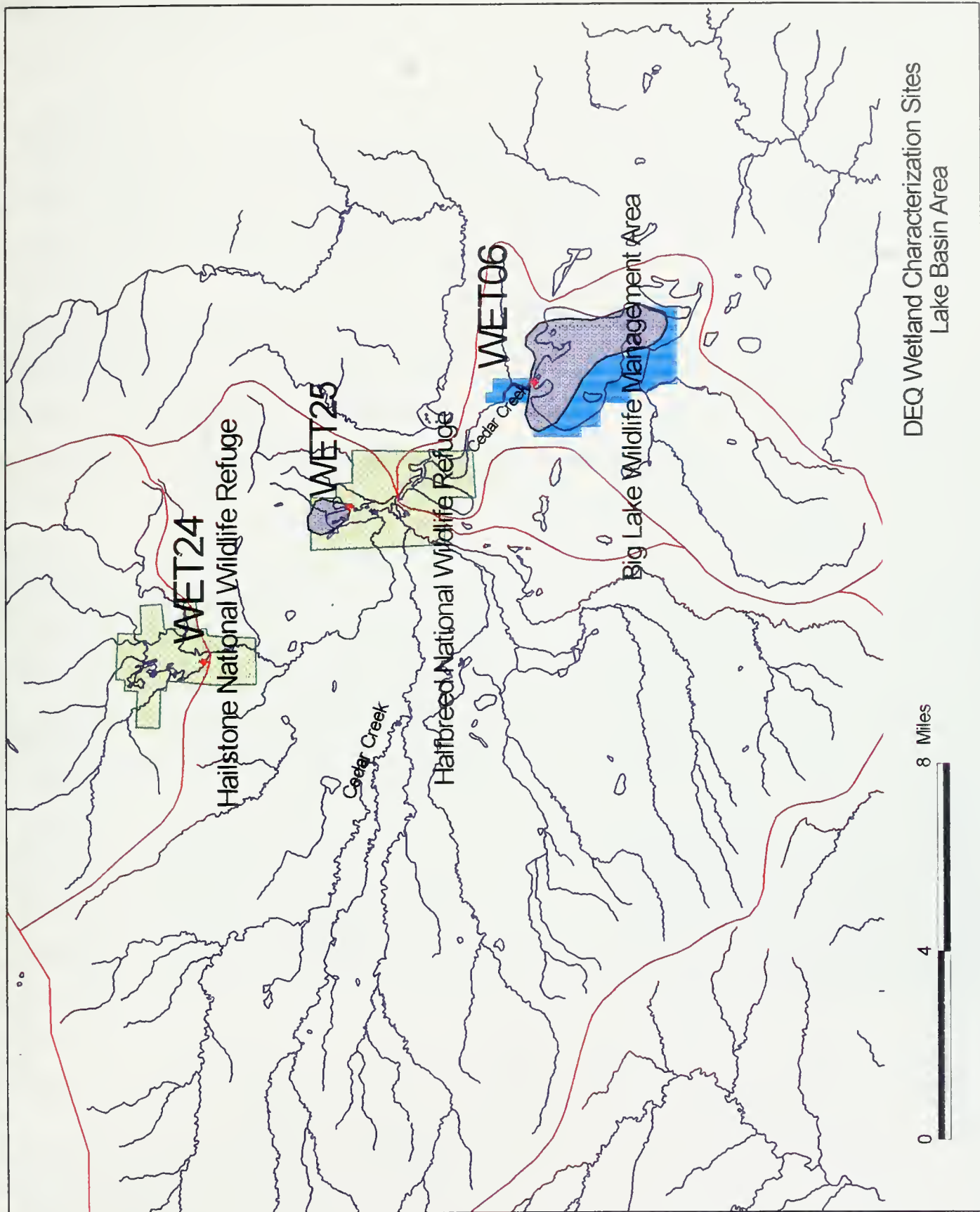


Concentrations in Milligrams per liter



HNO3 - Extractable Sediment Concentrations in PPM





DEQ Wetland Characterization Sites
Lake Basin Area

Wetland: BIG LAKE

Site Code: WET06

7.5 Minute Quad: WHEAT BASIN

Lat: 45 54 5

Long: 109 3 35

Mean Annual Precipitation in Inches: 13.00

Mean Annual Potential Evaporation (Penman) in Inches: 41.00

'Net Precipitation' in Inches: -28.00

Site has a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 3081 acres

Area of contributing drainage basin: 24420 acres

Mapped elevation of wetland surface: 3148 ft

Maximum elevation within drainage basin: 5200 ft

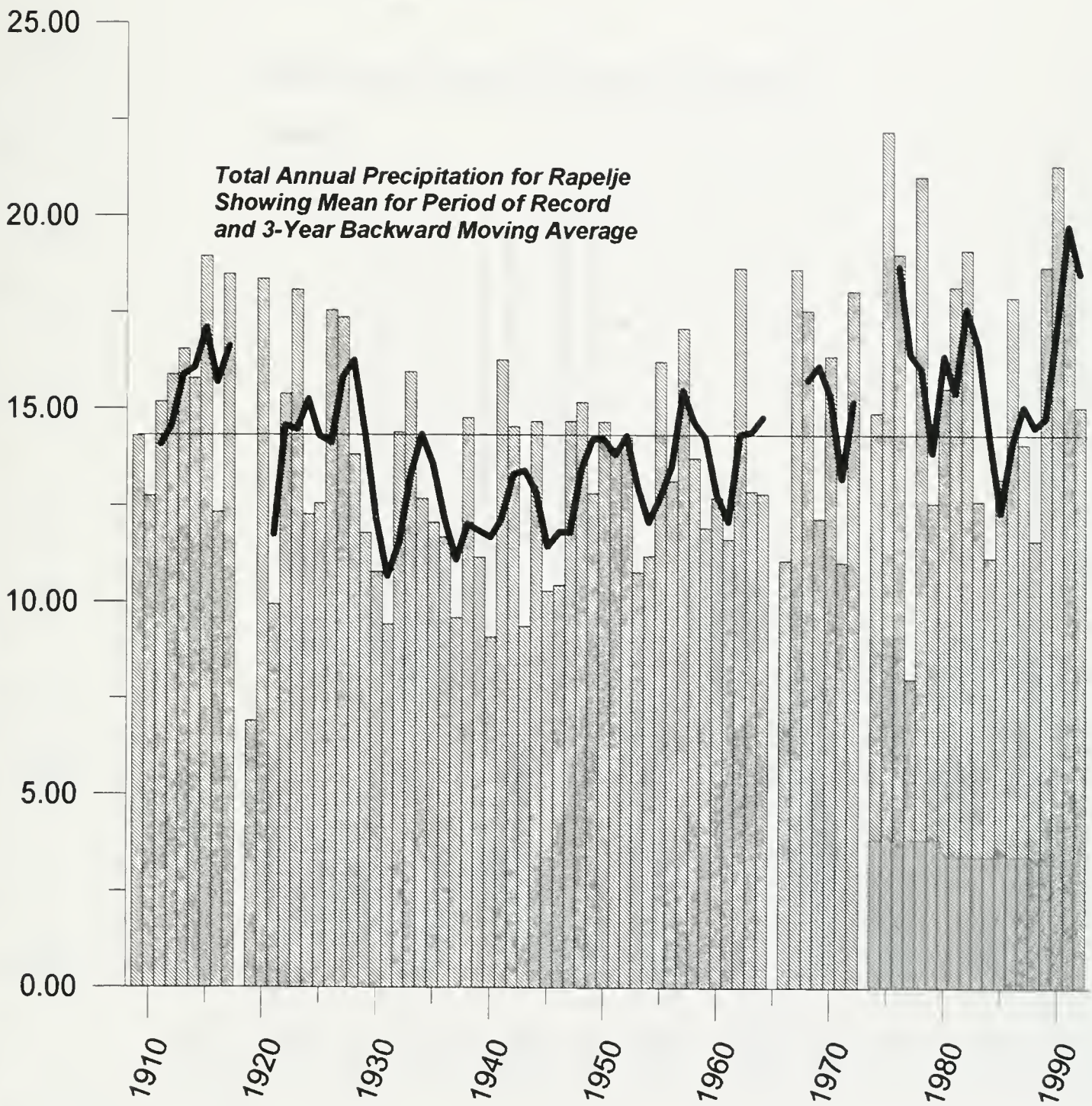
Net relief of contributing basin: 2052 ft

COE Hydrogeomorphic class: DEPRESSIONAL

Primary surficial geologic unit 110"LAC"

Primary bedrock geologic unit 211JDRV

Annual Precipitation in Inches



10.00

Monthly Average, Maximum and Minimum Precipitation

Rapelje

8.00

6.00

4.00

2.00

0.00

jan

feb

mar

apr

may

june

july

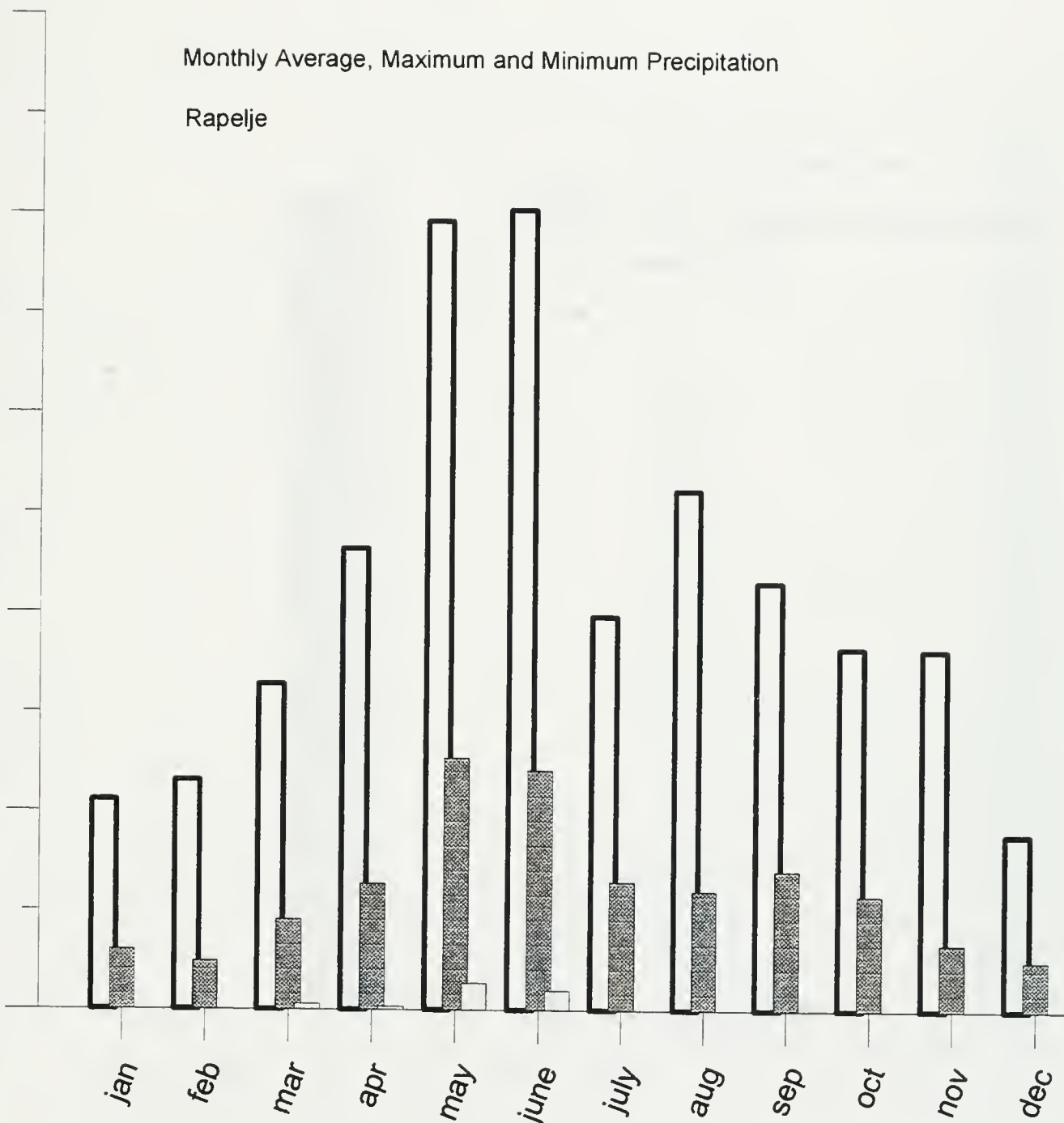
aug

sep

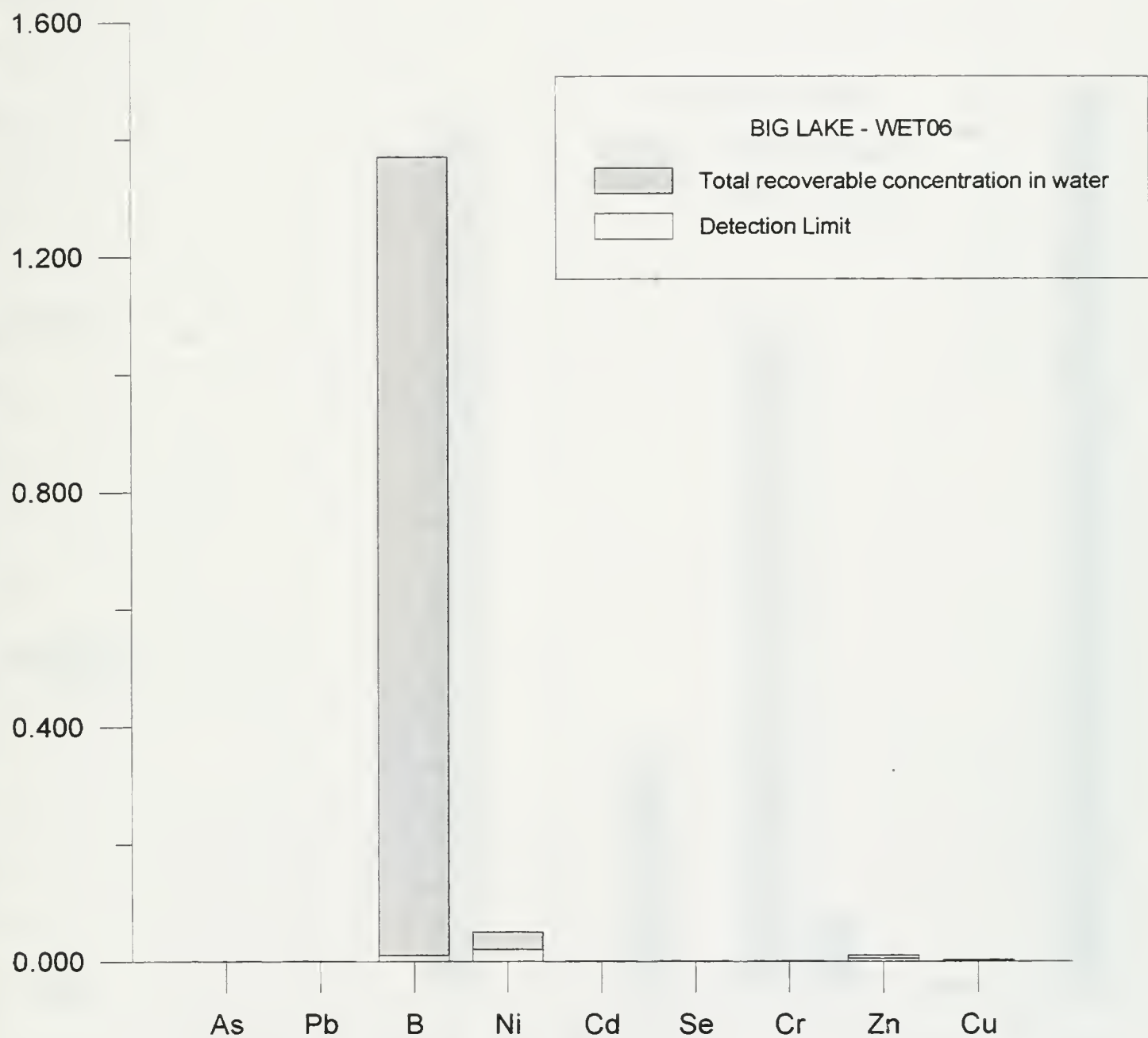
oct

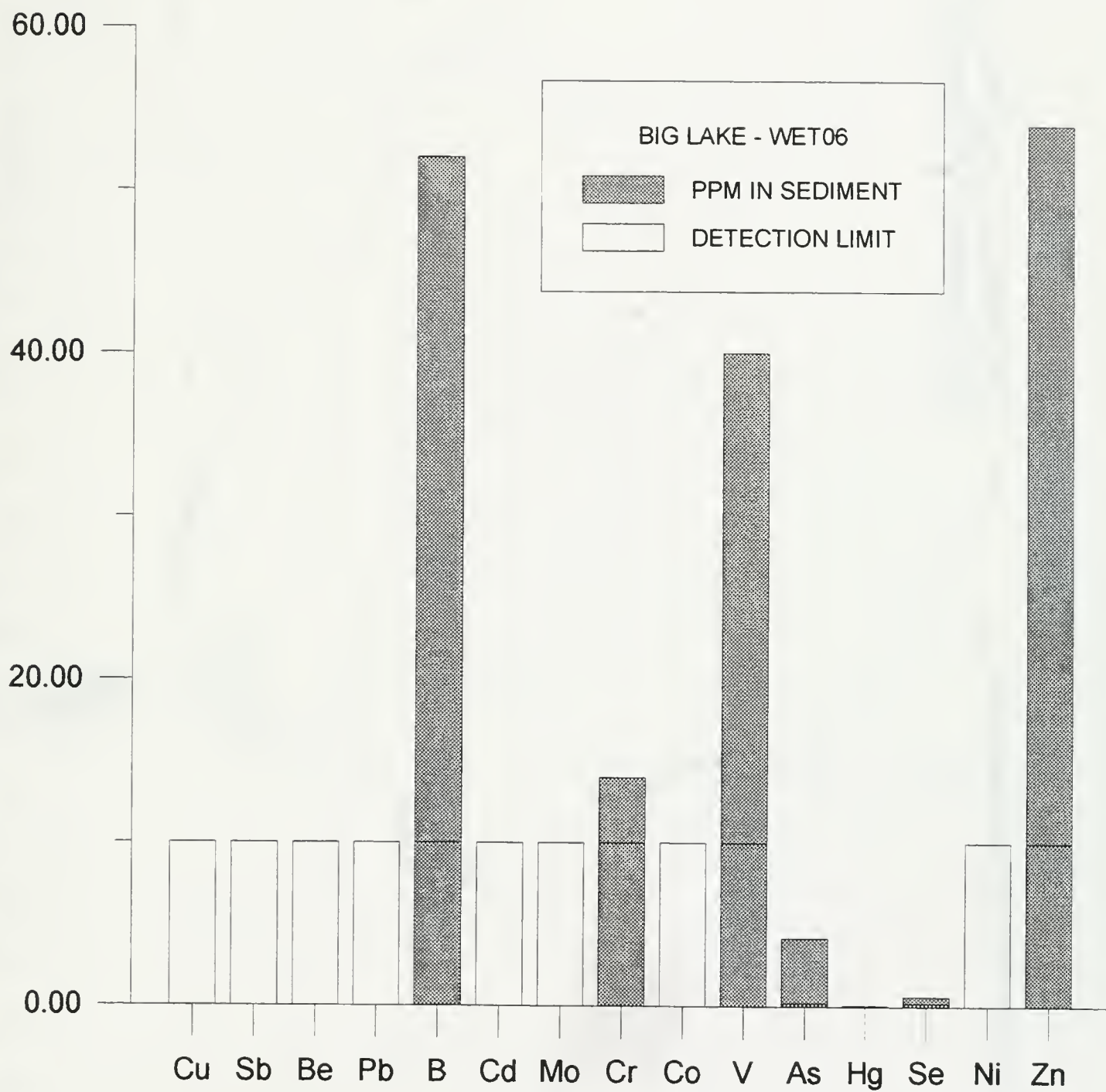
nov

dec

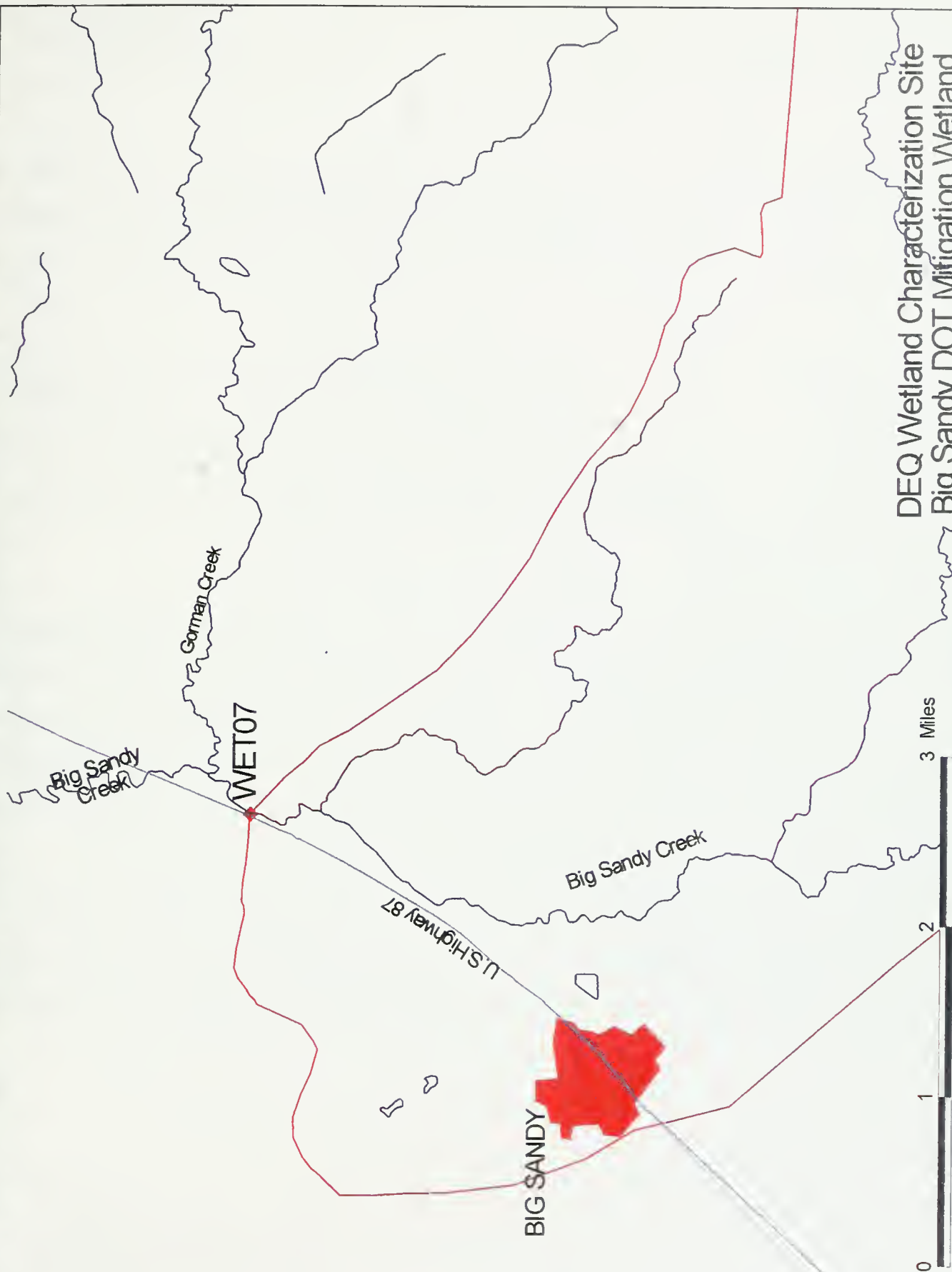


Concentrations in Milligrams per liter





DEQ Wetland Characterization Site
Big Sandy DOT Mitigation Wetland



Wetland: BIG SANDY DOT MITIGATION WETLAND

Site Code: WET07

7.5 Minute Quad: BIG SANDY

Lat: 48 12 35

Long: 110 4 50

Mean Annual Precipitation in Inches: 13.00

Mean Annual Potential Evaporation (Penman) in Inches: 39.00

'Net Precipitation' in Inches: -26.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 10 acres

Area of contributing drainage basin: 61800 acres

Mapped elevation of wetland surface: 2673 ft

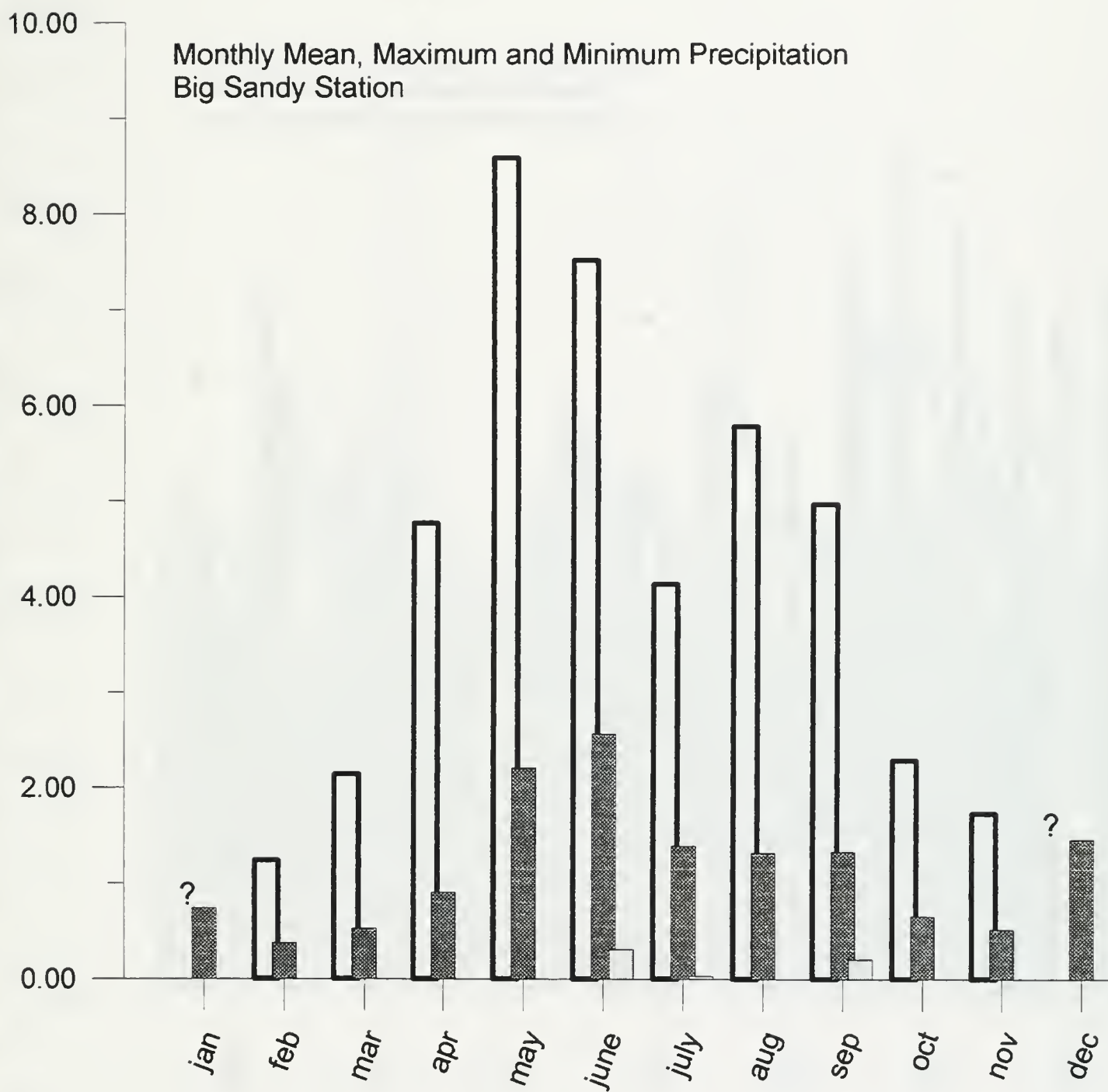
Maximum elevation within drainage basin: 6321 ft

Net relief of contributing basin: 3648 ft

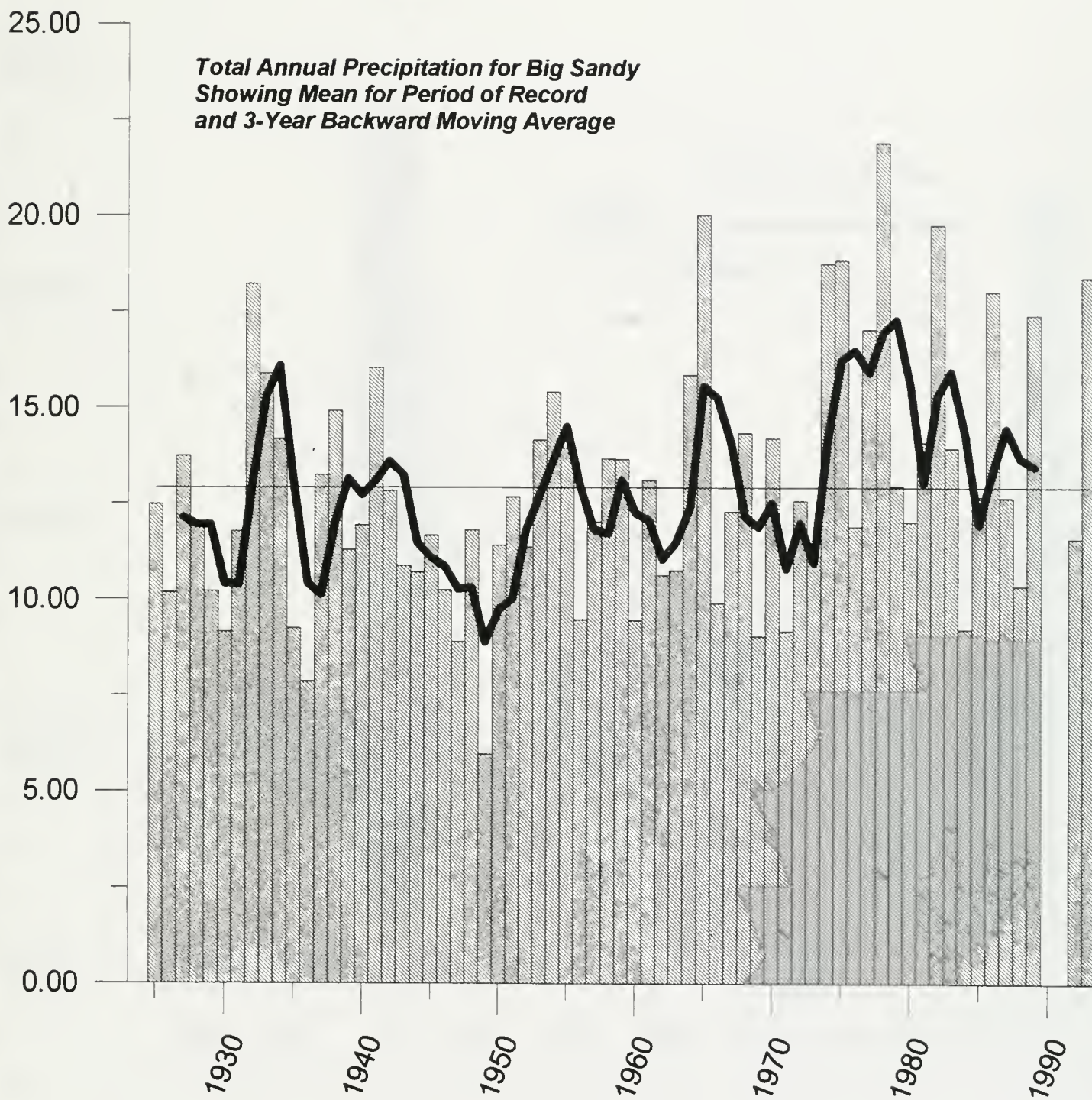
COE Hydrogeomorphic class: RIVERINE

Primary surficial geologic unit 110ALVM

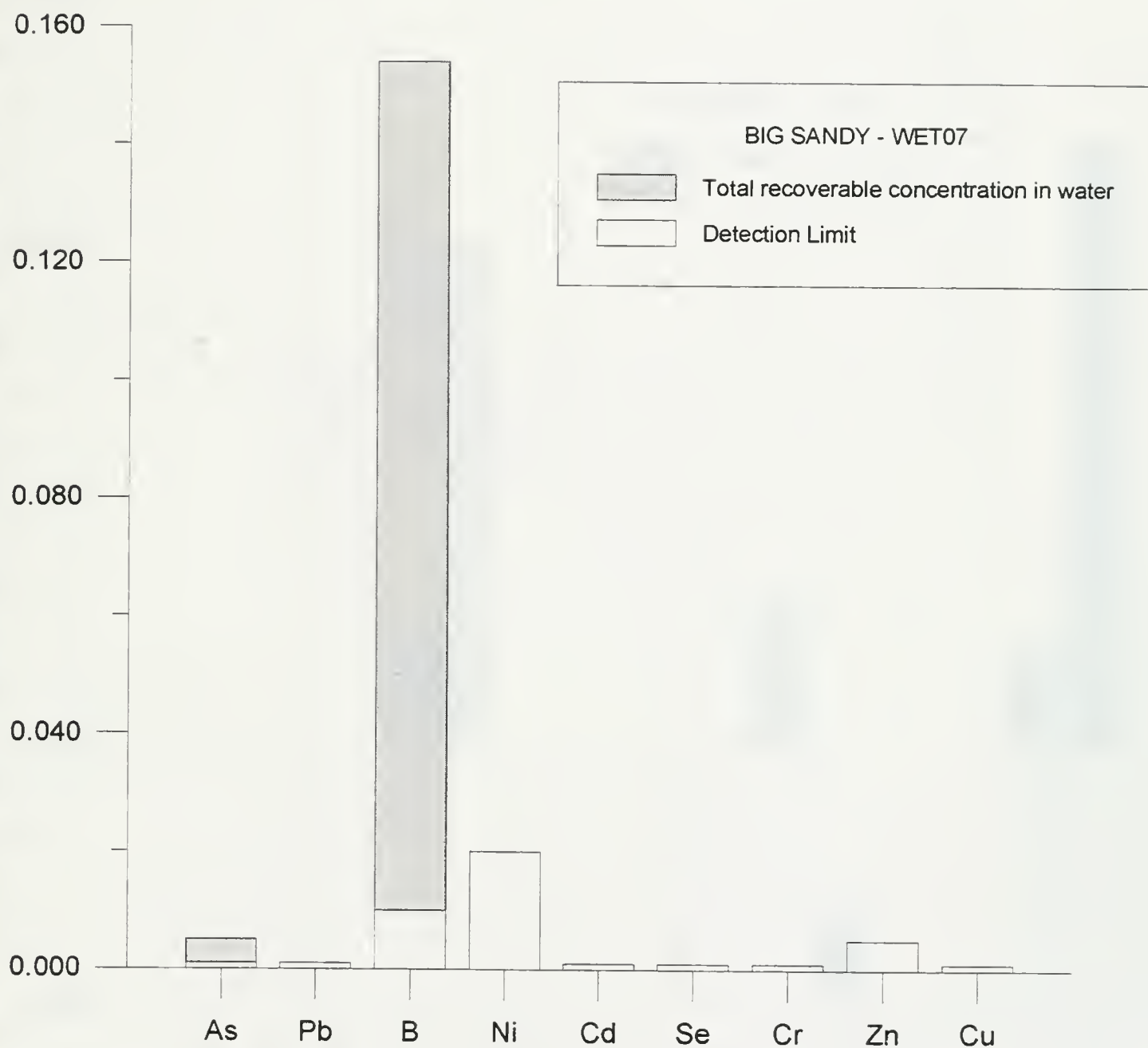
Primary bedrock geologic unit 211CLGG

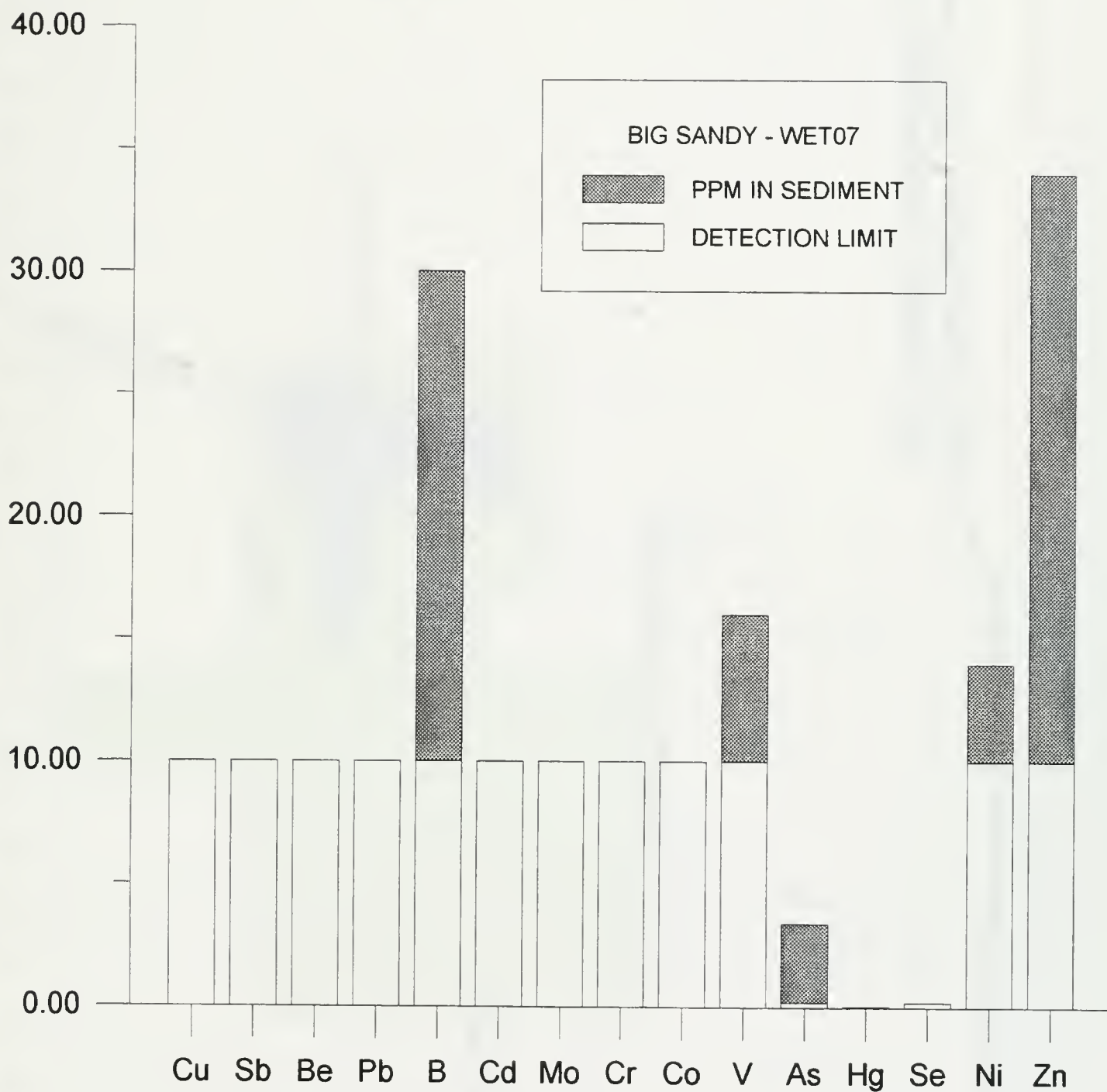


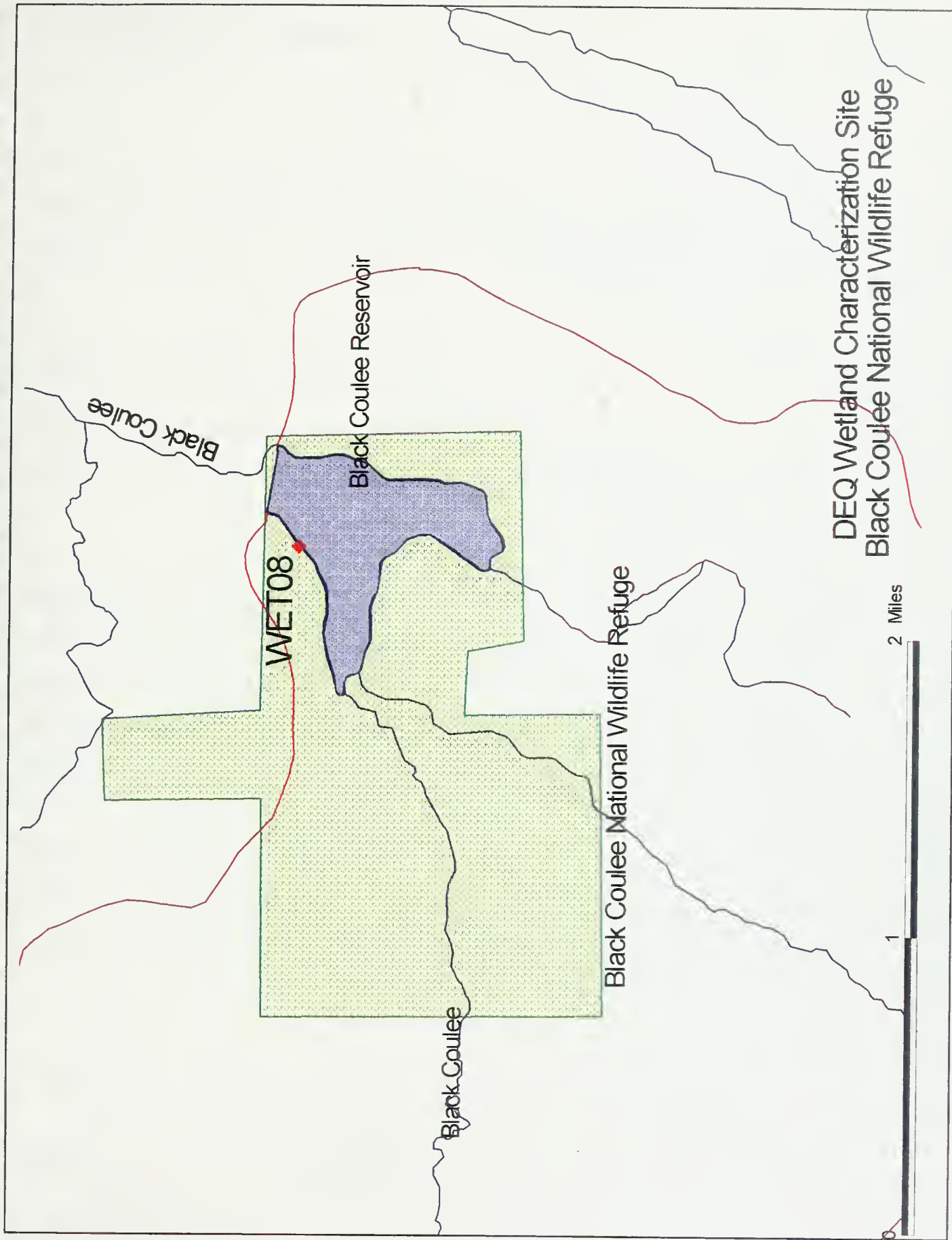
Annual Precipitation in Inches



Concentrations in Milligrams per liter







DEQ Wetland Characterization Site
Black Coulee National Wildlife Refuge

2 Miles

1

0

Wetland: BLACK COULEE NWR

Site Code: WET08

7.5 Minute Quad: DOWN RESERVOIR NORTHWEST

Lat: 48 41 45

Long: 108 24 0

Mean Annual Precipitation in Inches: 11.00

Mean Annual Potential Evaporation (Penman) in Inches: 37.00

'Net Precipitation' in Inches: -26.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 170 acres

Area of contributing drainage basin: 8330 acres

Mapped elevation of wetland surface: 2903 ft

Maximum elevation within drainage basin: 3140 ft

Net relief of contributing basin: 237 ft

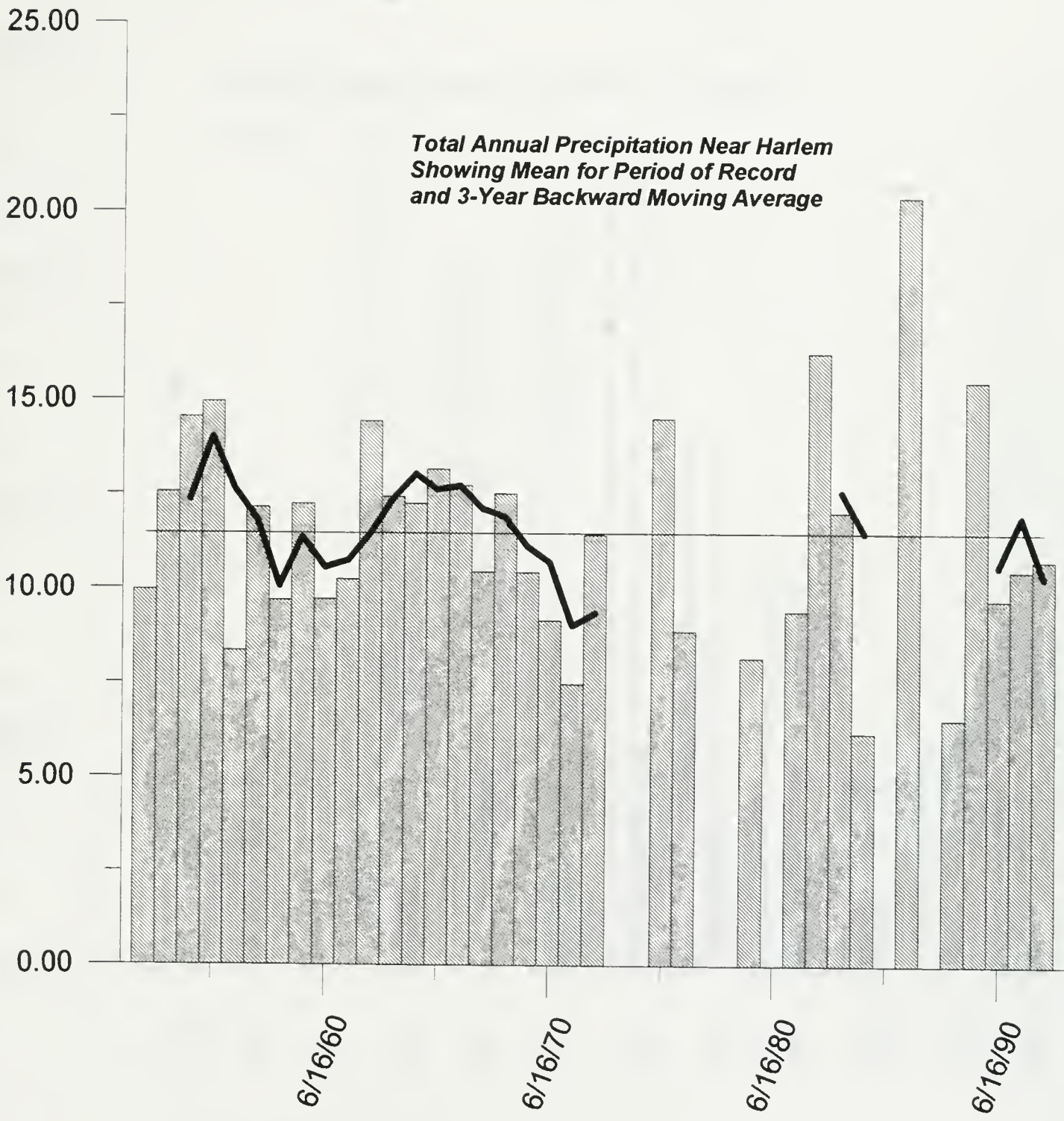
COE Hydrogeomorphic class: FRINGE

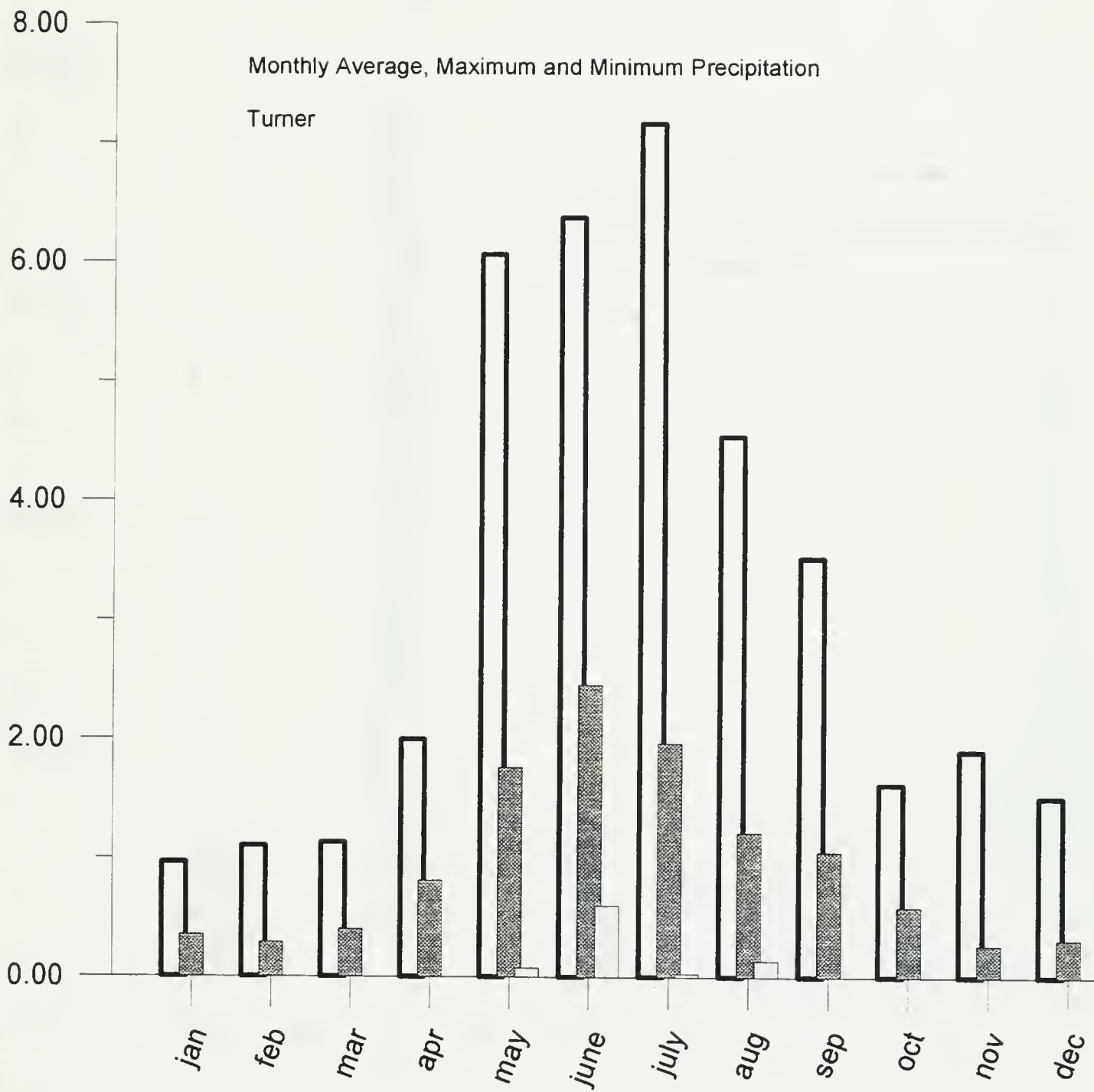
Primary surficial geologic unit 112TILL

Primary bedrock geologic unit 211BRPW

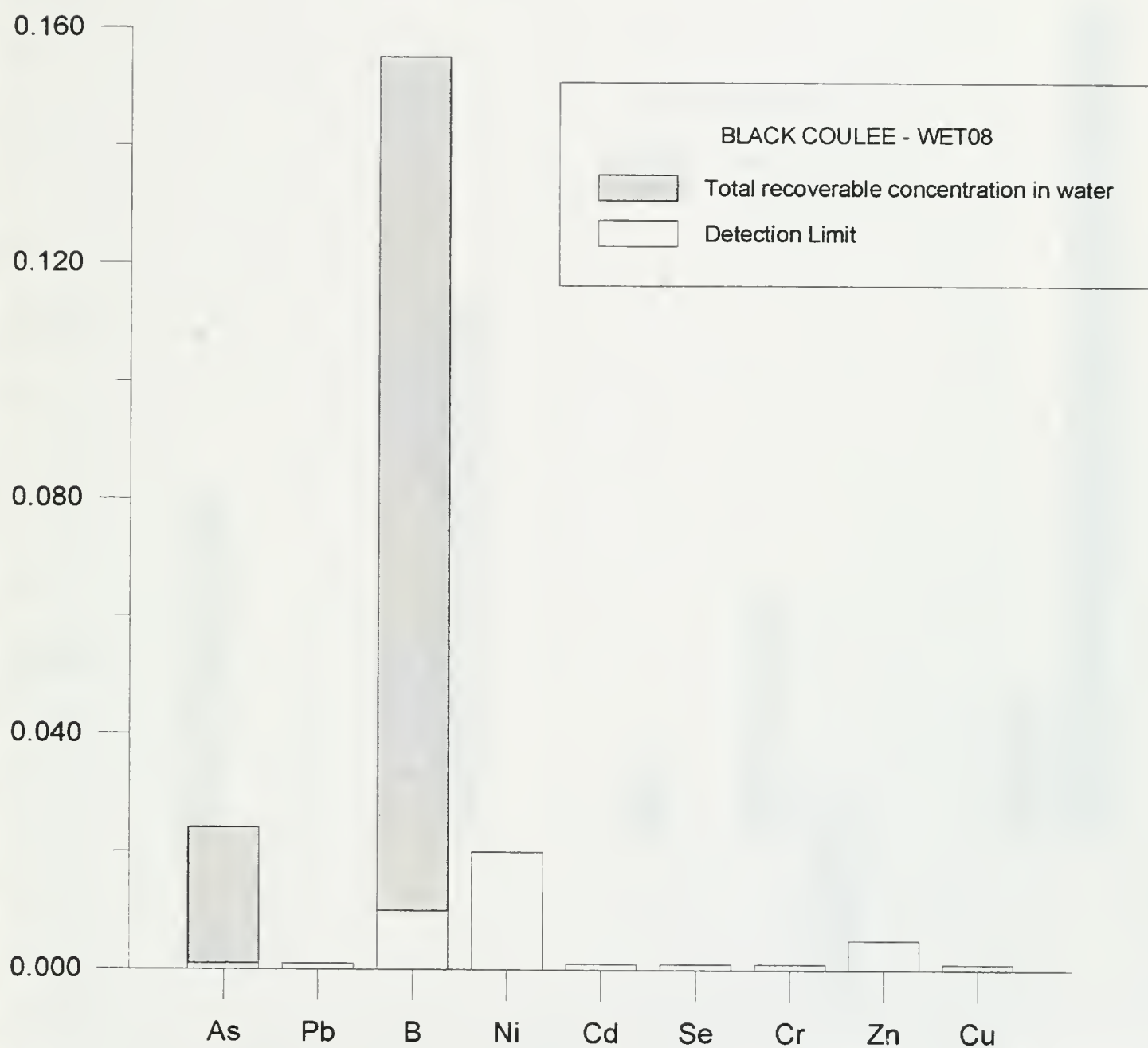
Annual Precipitation in Inches

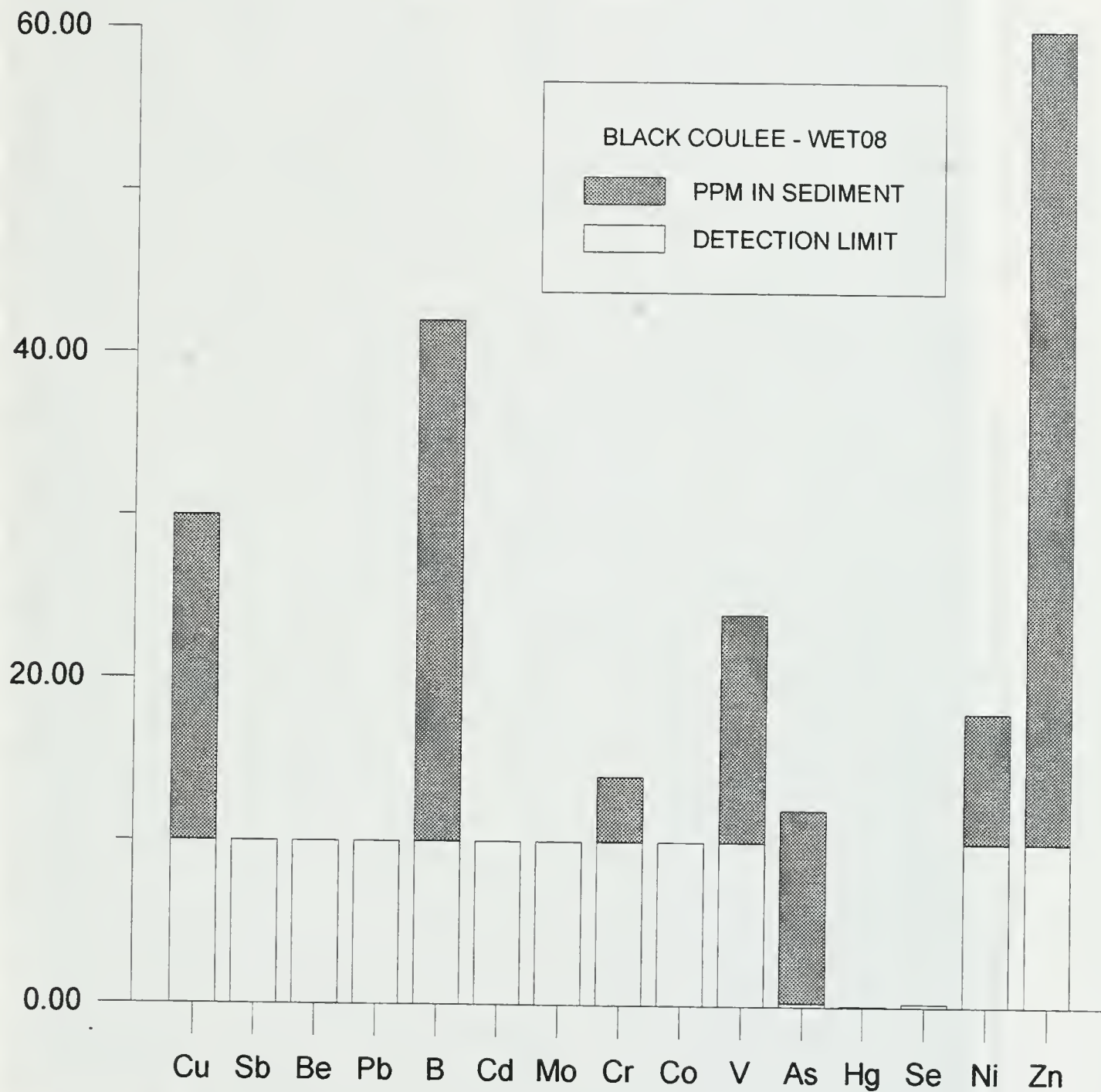
*Total Annual Precipitation Near Harlem
Showing Mean for Period of Record
and 3-Year Backward Moving Average*

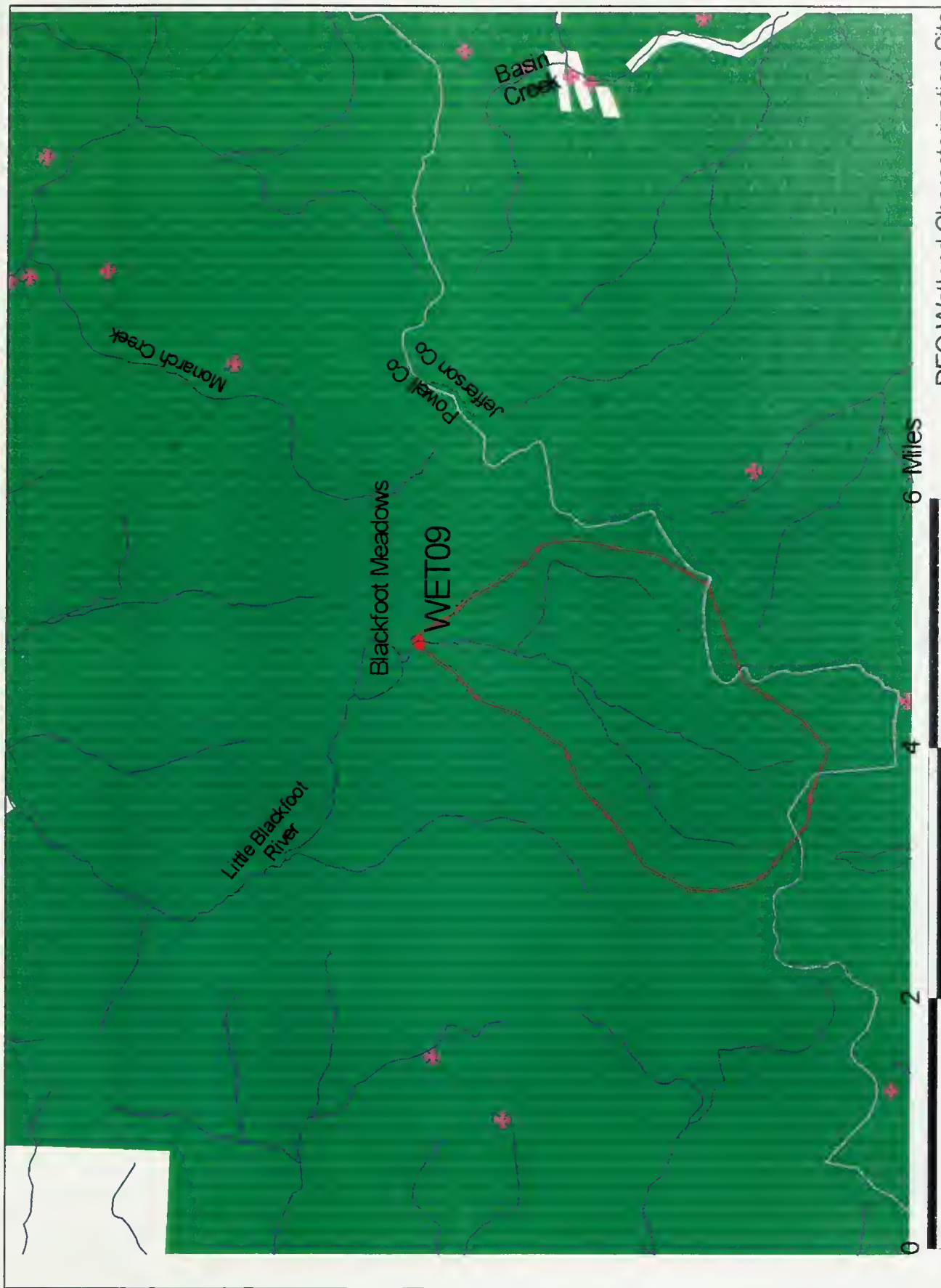




Concentrations in Milligrams per liter







DEQ Wetland Characterization Site
Blackfoot Meadows

Wetland: BLACKFOOT MEADOWS

Site Code: WET09

7.5 Minute Quad: BISON MOUNTAIN

Lat: 46 23 0

Long: 112 26 50

Mean Annual Precipitation in Inches: 25.00

Mean Annual Potential Evaporation (Penman) in Inches: 27.00

'Net Precipitation' in Inches: -2.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 50 acres

Area of contributing drainage basin: 3180 acres

Mapped elevation of wetland surface: 6610 ft

Maximum elevation within drainage basin: 8597 ft

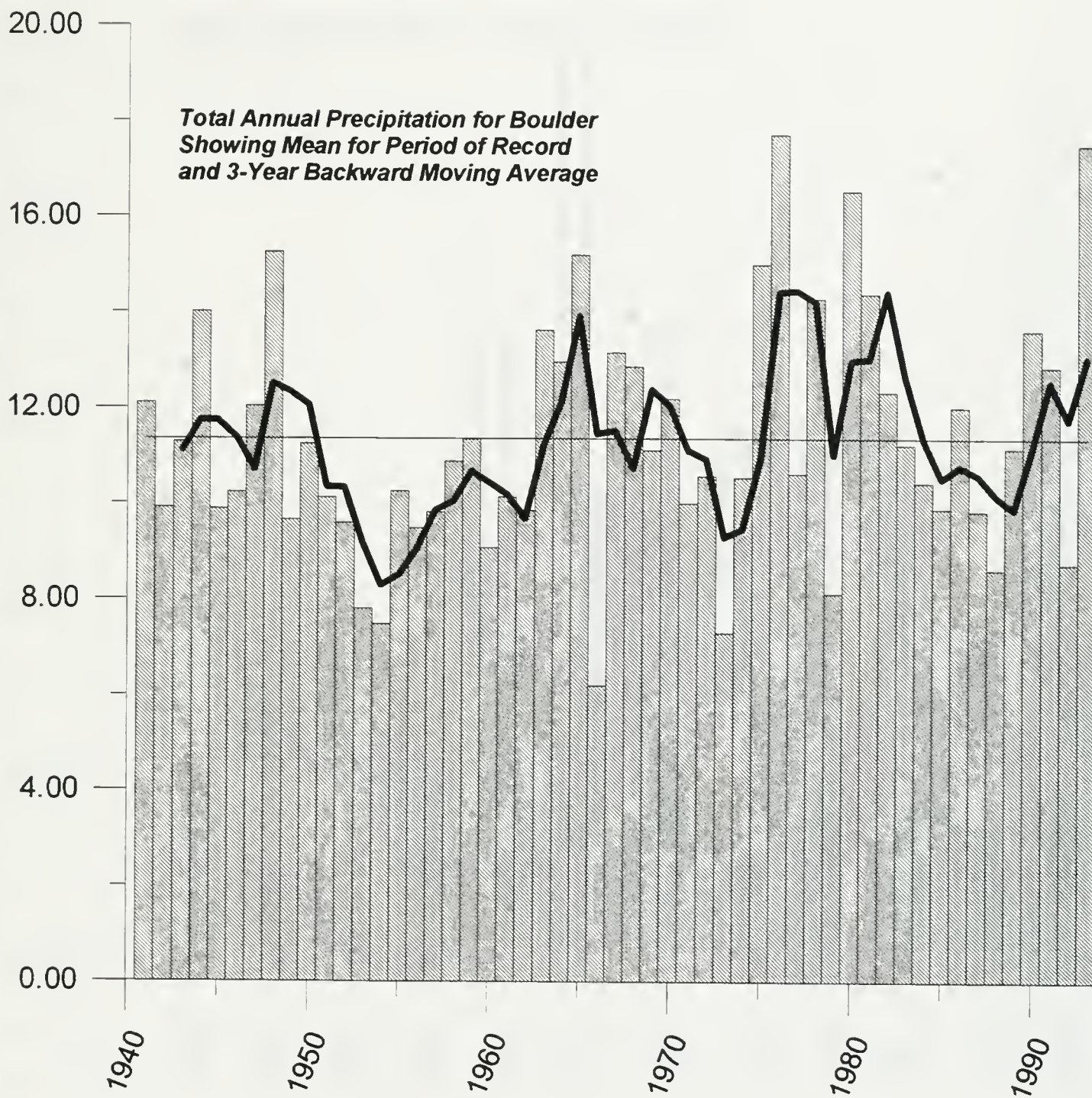
Net relief of contributing basin: 1987 ft

COE Hydrogeomorphic class: RIVERINE

Primary surficial geologic unit 110ALVM

Primary bedrock geologic unit 120VLCC

Annual Precipitation in Inches



Inches Precipitation

5.00

Monthly Average, Maximum and Minimum Precipitation
Basin Station

4.00

3.00

2.00

1.00

0.00

jan

feb

mar

apr

may

june

july

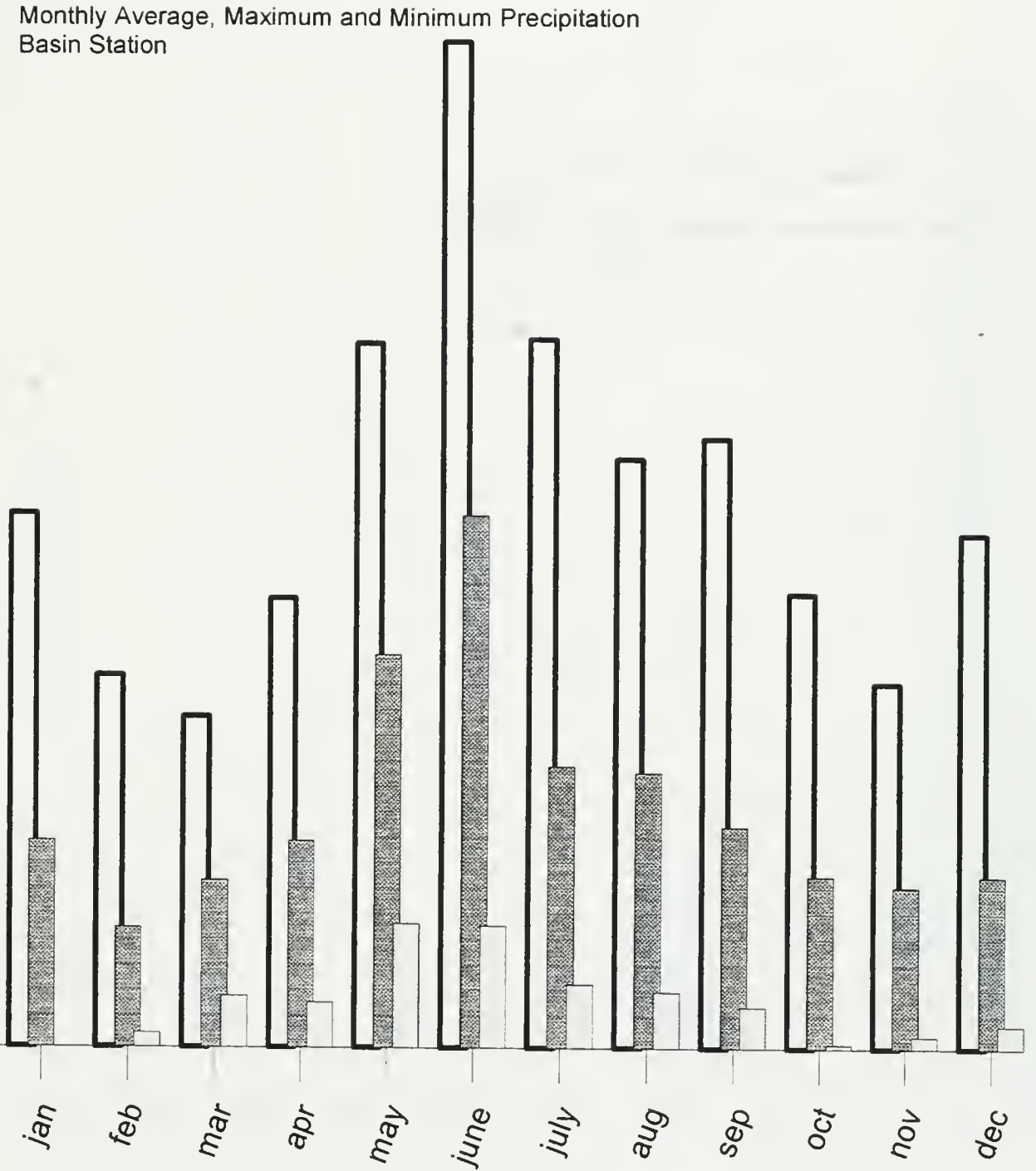
aug

sep

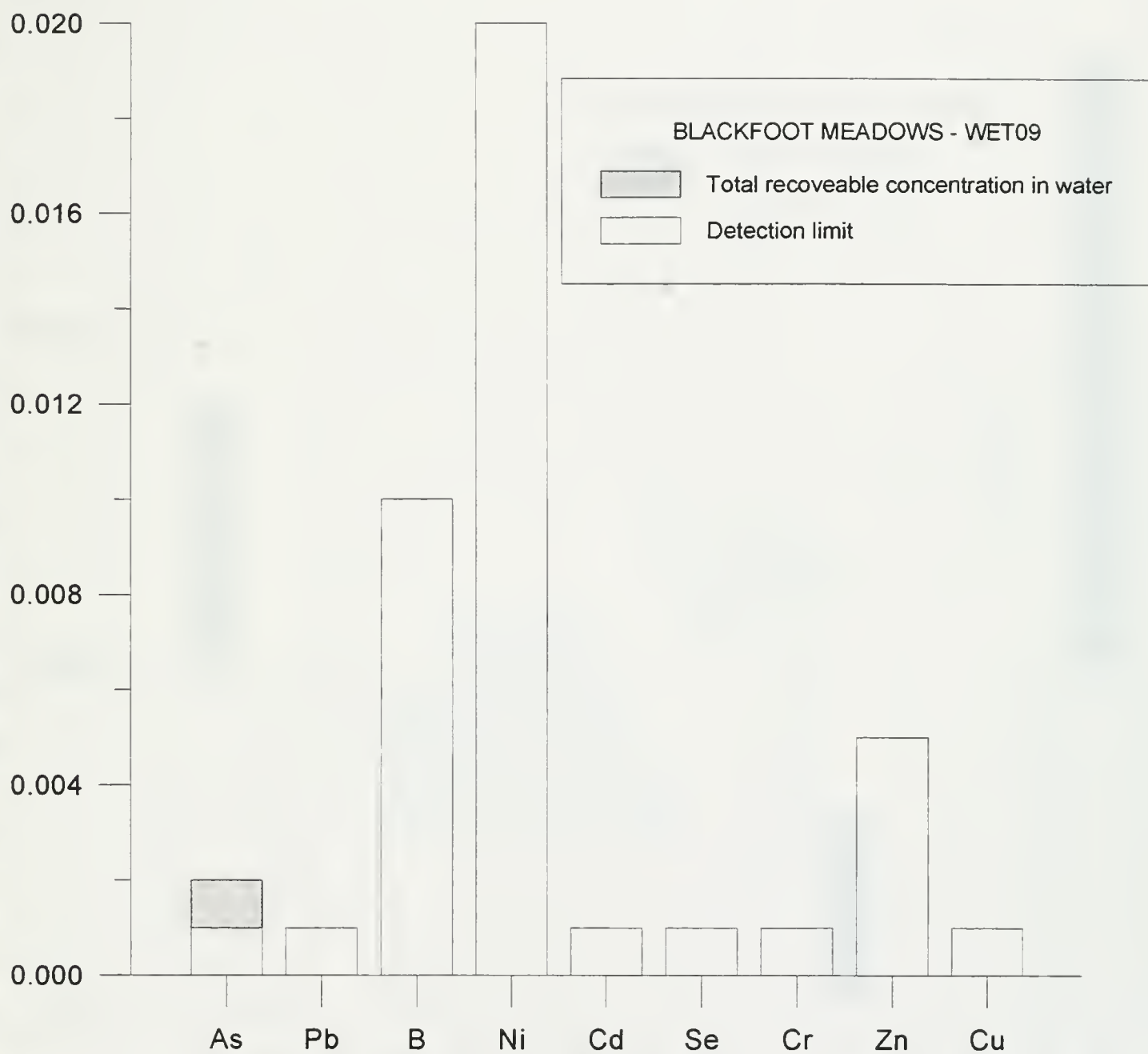
oct

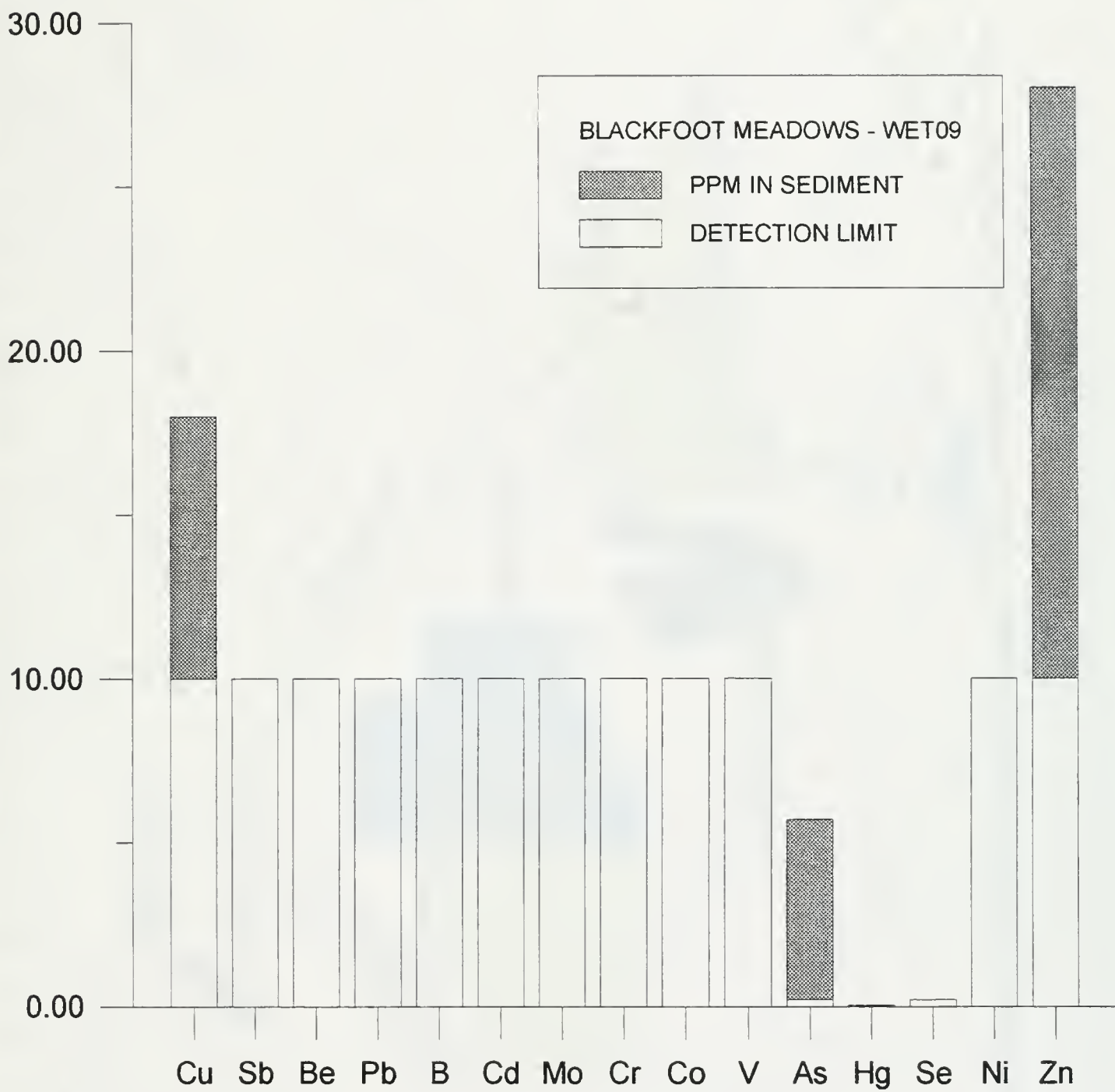
nov

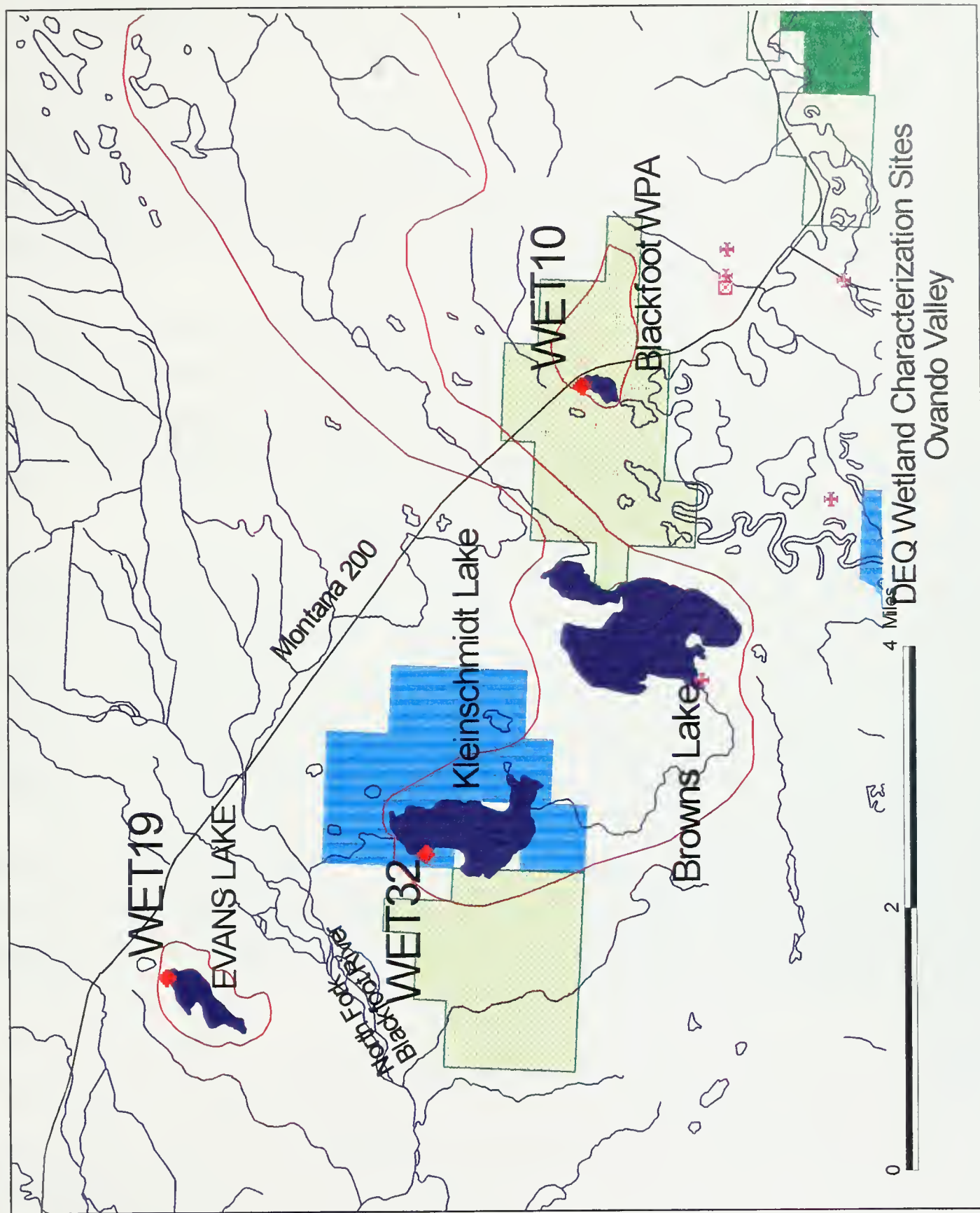
dec



Concentrations in Milligrams per liter







Wetland: BLACKFOOT WPA

Site Code: WET10

7.5 Minute Quad: MARCUM MOUNTAIN

Lat: 46 57 50

Long: 112 58 15

Mean Annual Precipitation in Inches: 19.00

Mean Annual Potential Evaporation (Penman) in Inches: 31.00

'Net Precipitation' in Inches: -12.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 20 acres

Area of contributing drainage basin: 320 acres

Mapped elevation of wetland surface: 4300 ft

Maximum elevation within drainage basin: 5880 ft

Net relief of contributing basin: 1580 ft

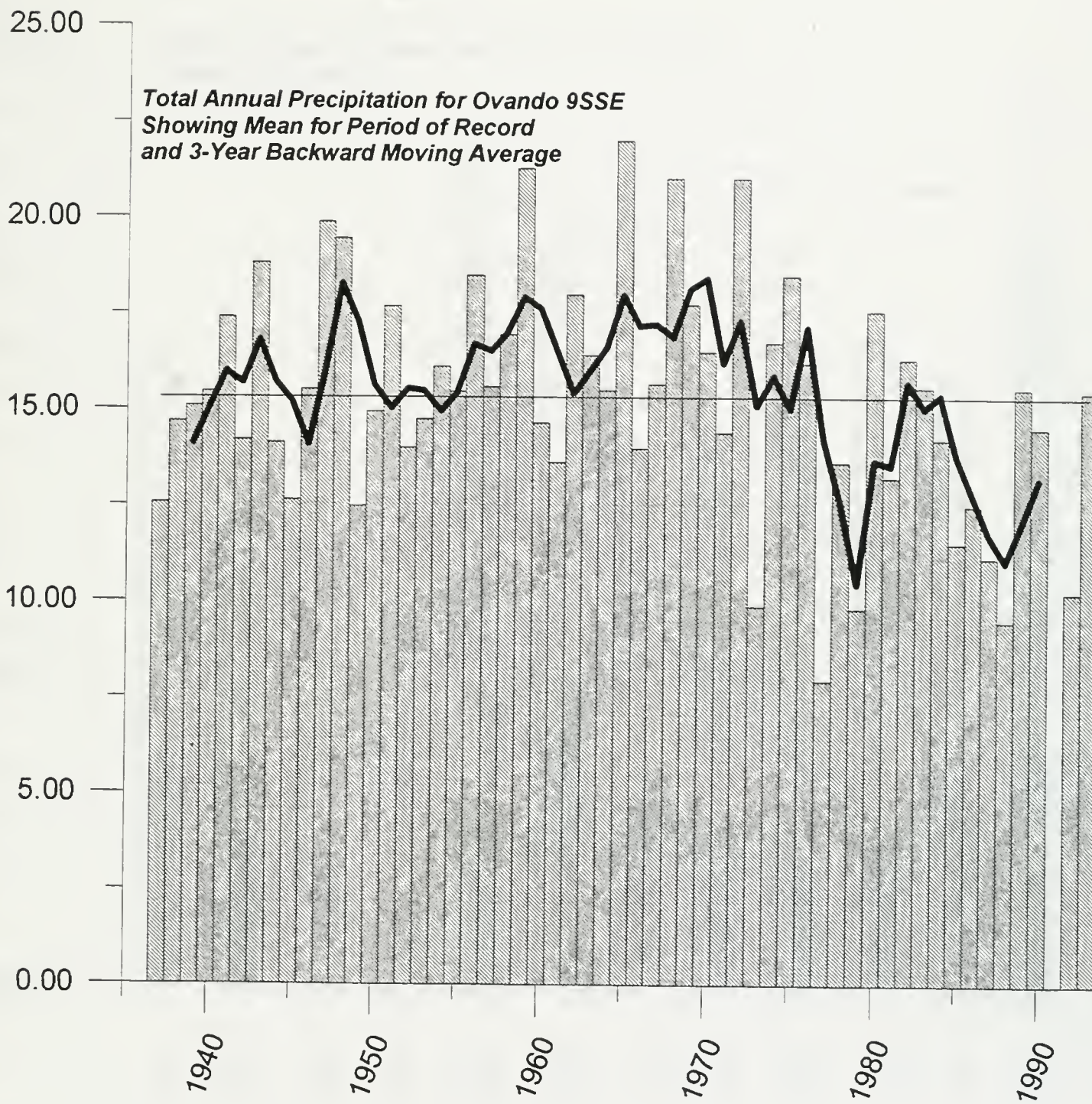
COE Hydrogeomorphic class: DEPRESSIONAL

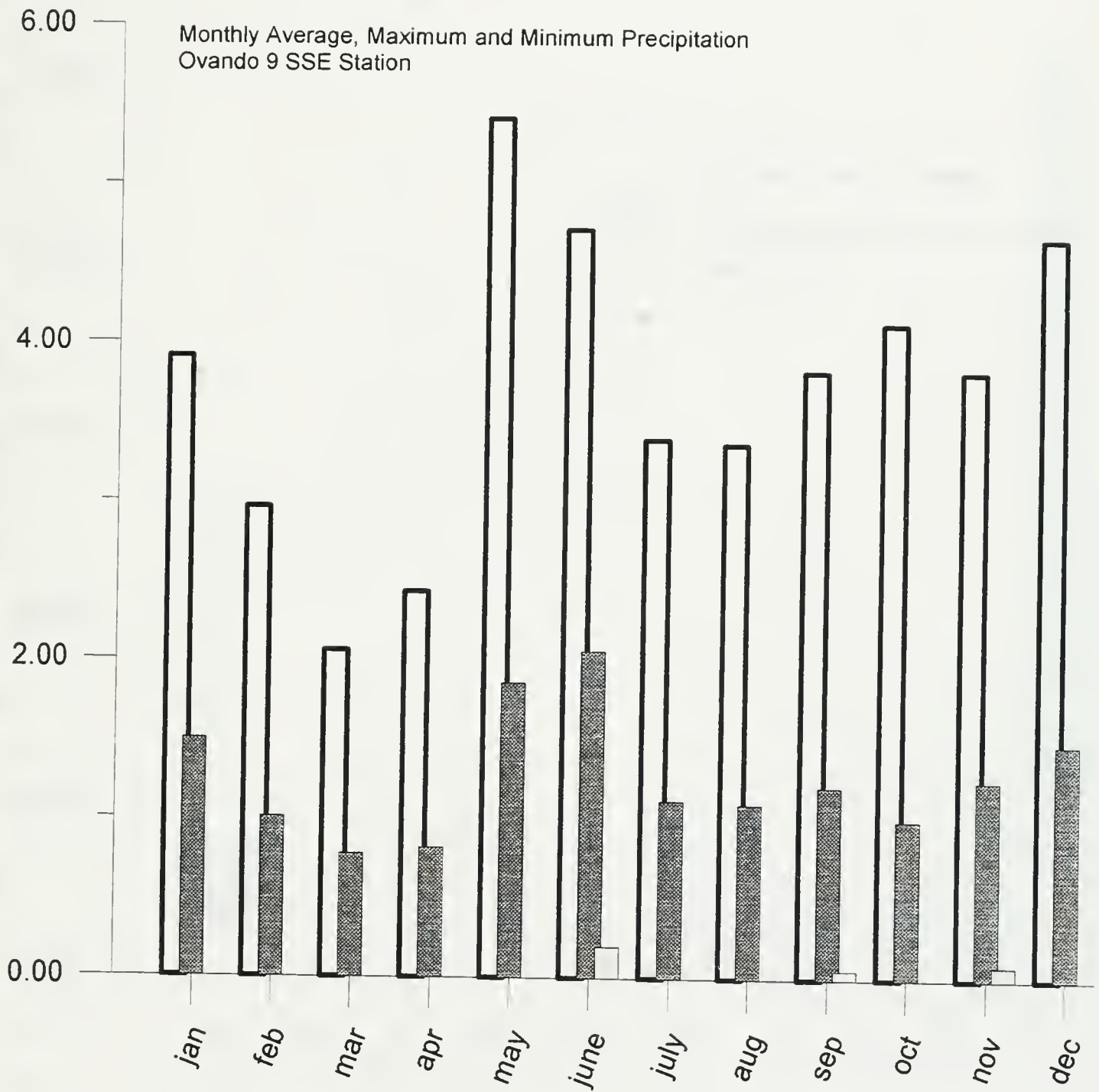
Primary surficial geologic unit 112DRFT

Primary bedrock geologic unit 400BELT

**Total Annual Precipitation for Ovando 9SSE
Showing Mean for Period of Record
and 3-Year Backward Moving Average**

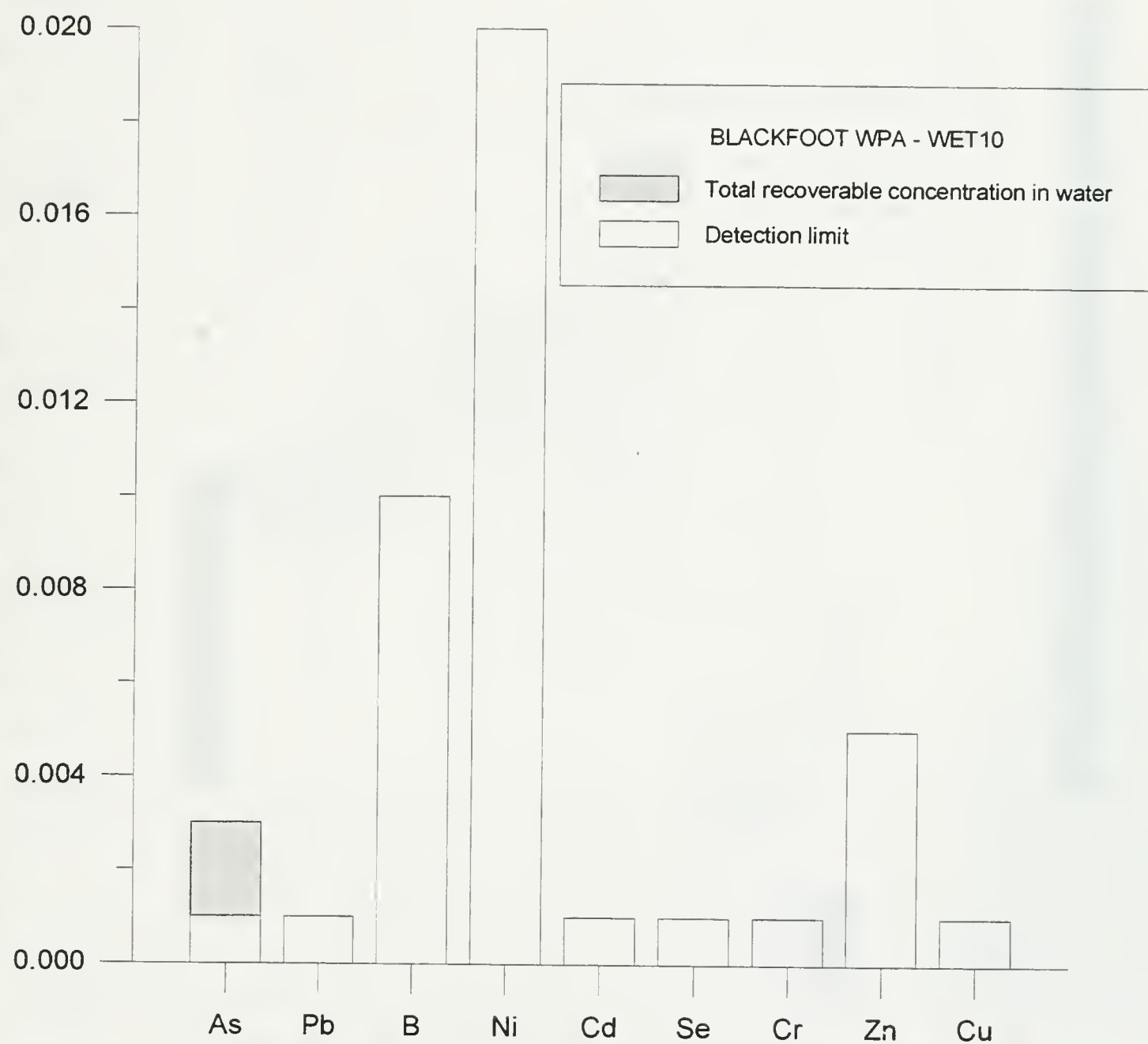
Annual Precipitation in Inches

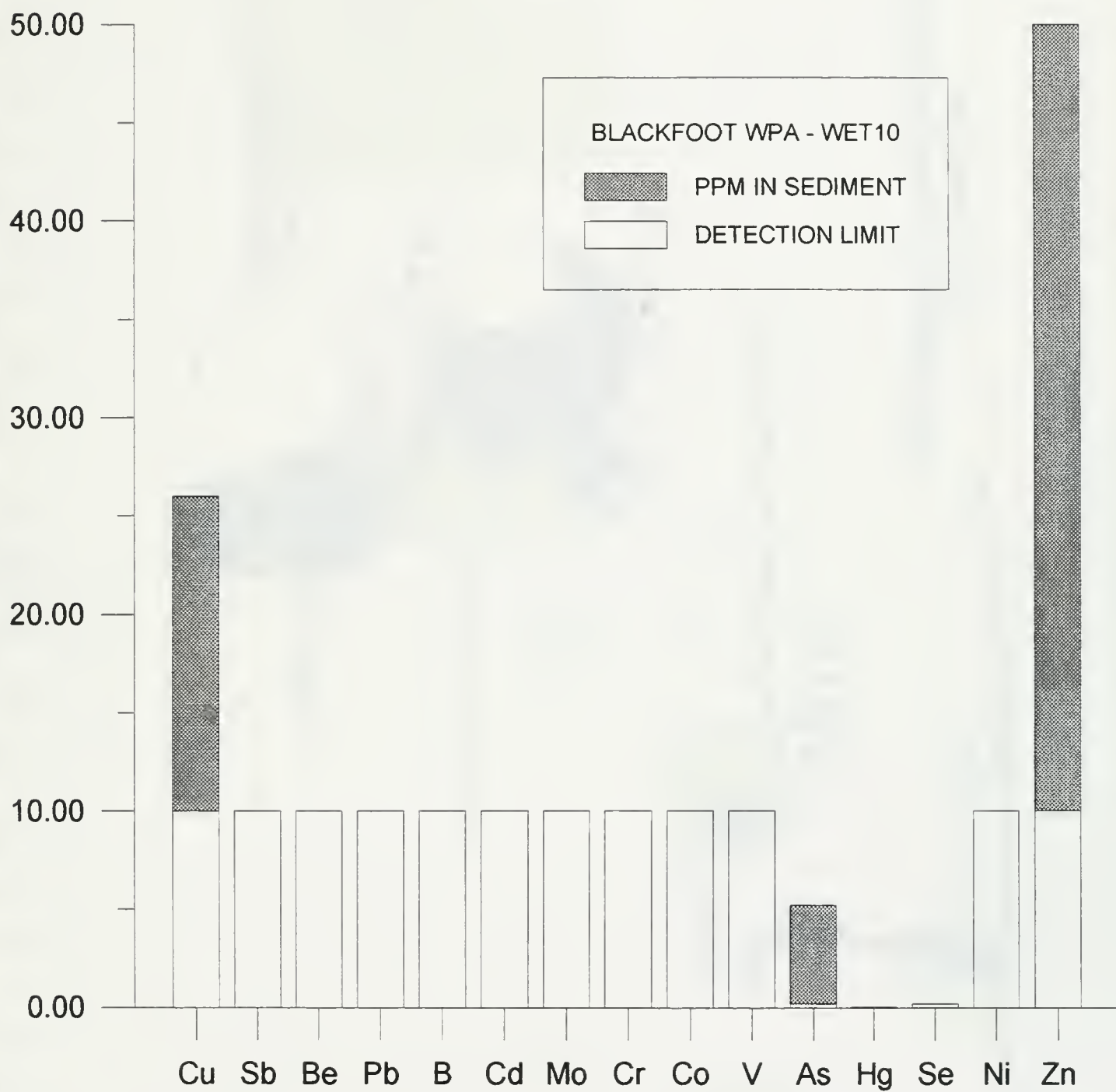


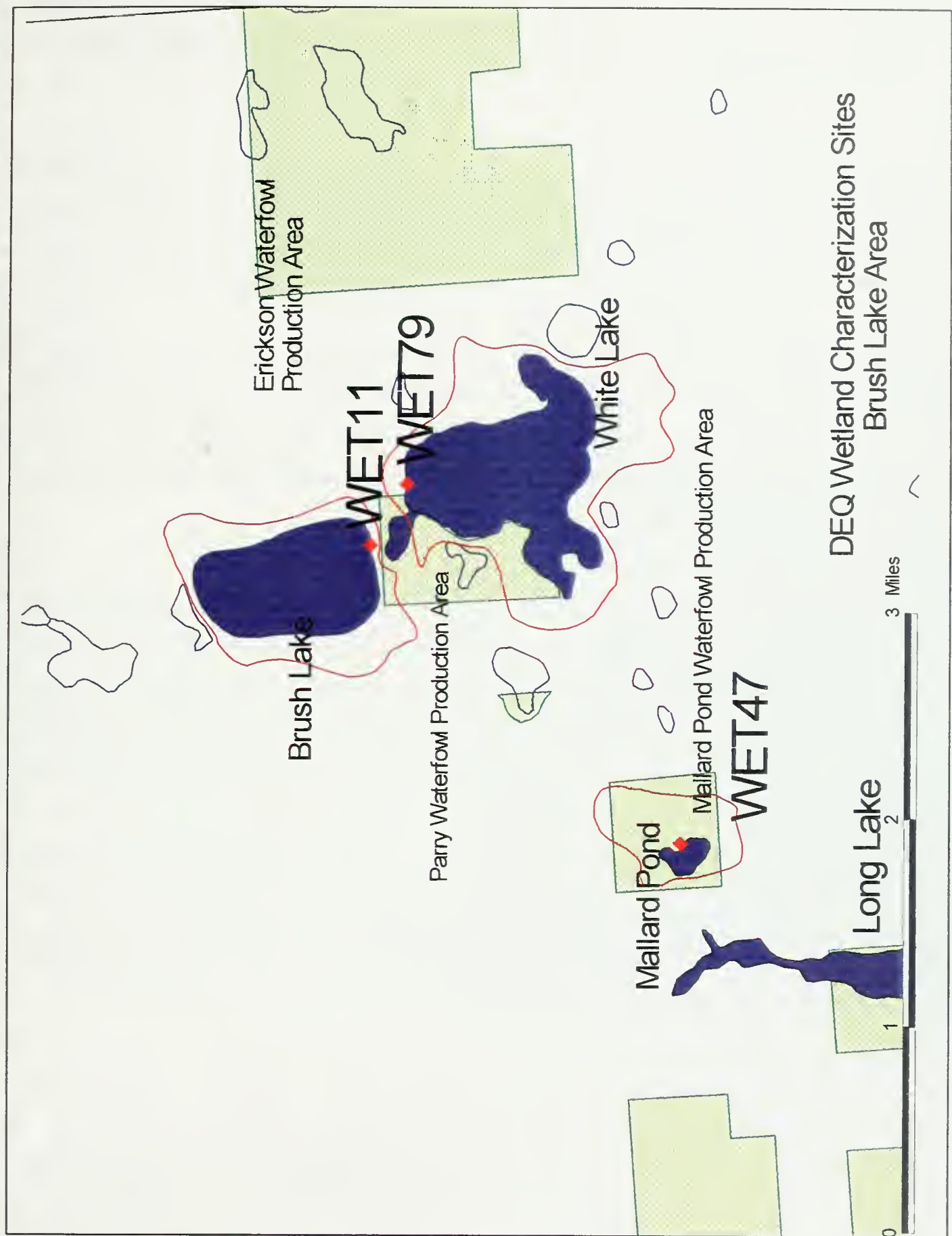


Concentrations in Milligrams per liter

BLACKFOOT WPA - WET10







Erickson Waterfowl
Production Area

Brush Lake

WET11
WET79

Parry Waterfowl Production Area

White Lake

Mallard Pond

Mallard Pond Waterfowl Production Area

WET47

Long Lake

DEQ Wetland Characterization Sites
Brush Lake Area

3 Miles

Wetland: BRUSH LAKE

Site Code: WET11

7.5 Minute Quad: BRUSH LAKE

Lat: 48 35 35

Long: 104 6 20

Mean Annual Precipitation in Inches: 13.00

Mean Annual Potential Evaporation (Penman) in Inches: 36.00

'Net Precipitation' in Inches: -23.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 250 acres

Area of contributing drainage basin: 460 acres

Mapped elevation of wetland surface: 1956 ft

Maximum elevation within drainage basin: 2022 ft

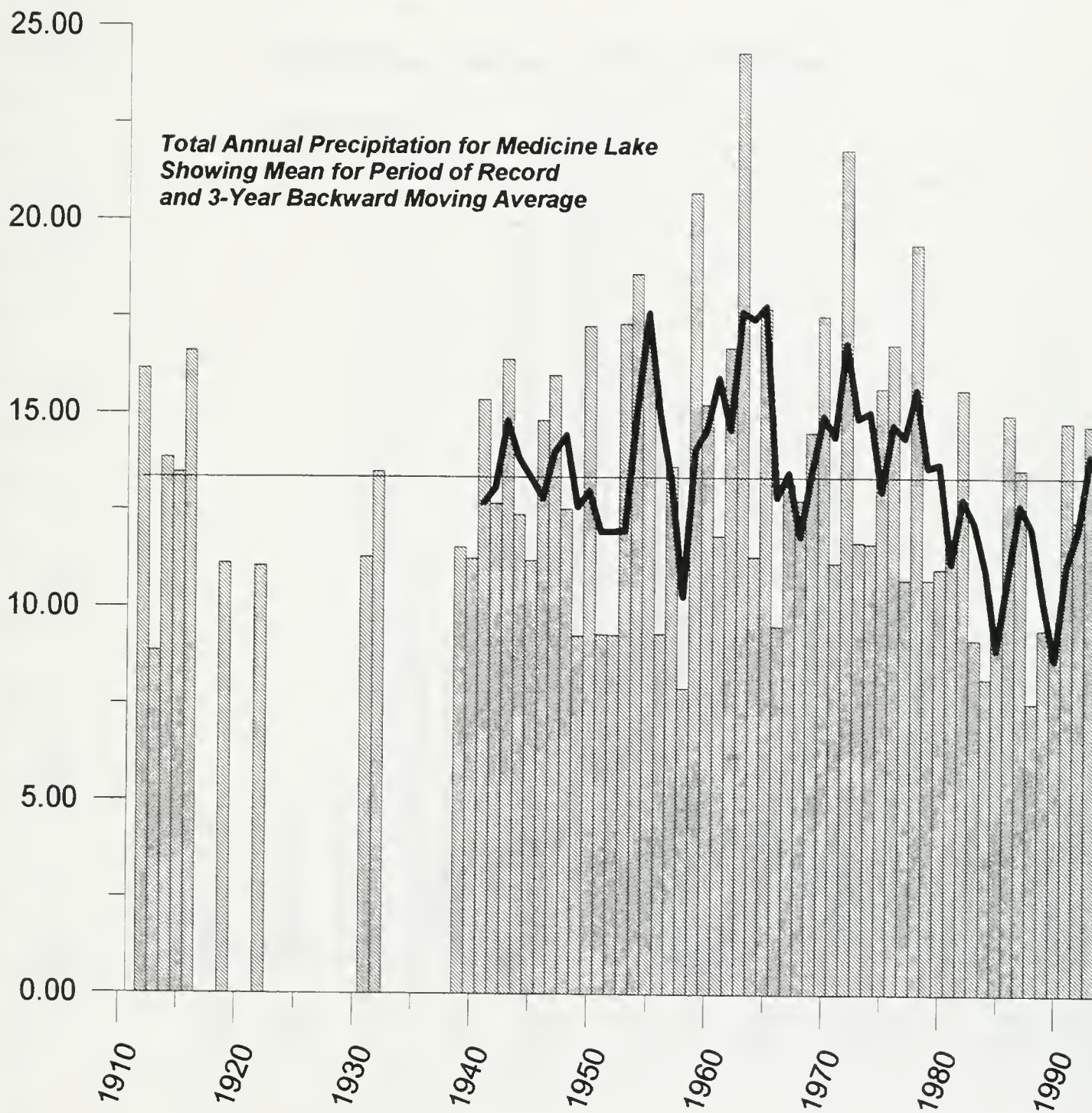
Net relief of contributing basin: 66 ft

COE Hydrogeomorphic class: FRINGE

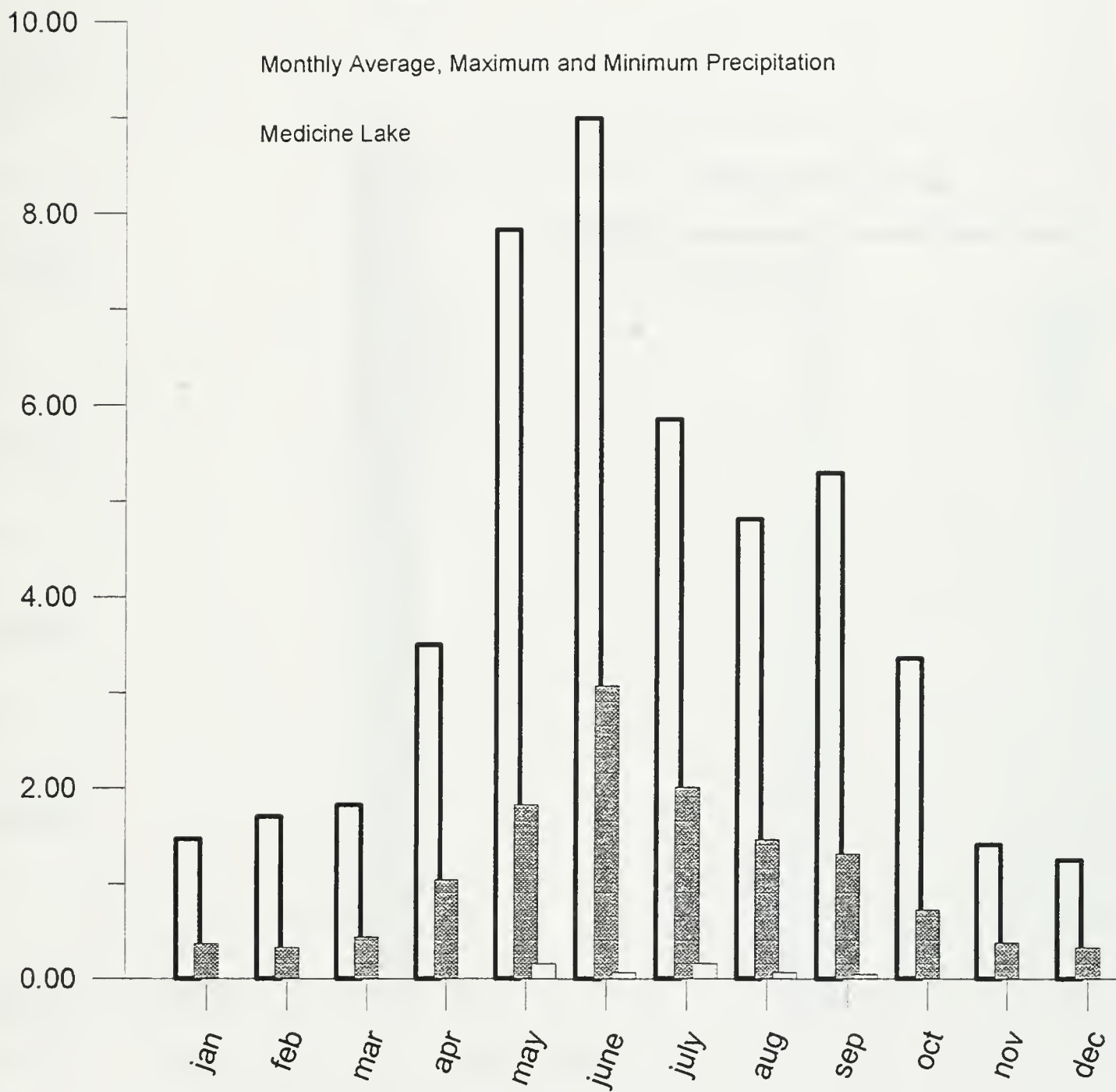
Primary surficial geologic unit 112OTSH

Primary bedrock geologic unit 125FRUN

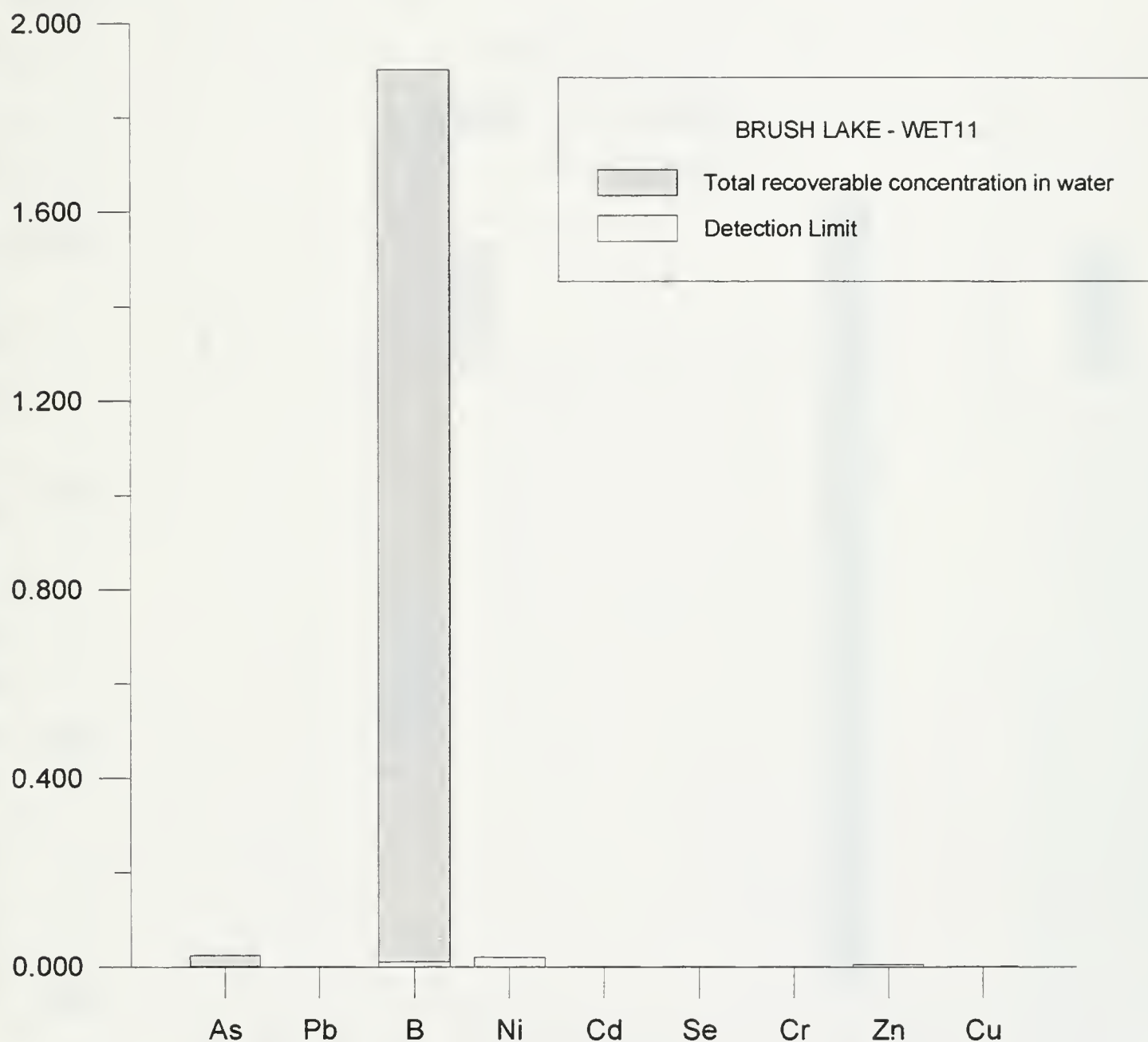
Total Annual Precipitation in Inches

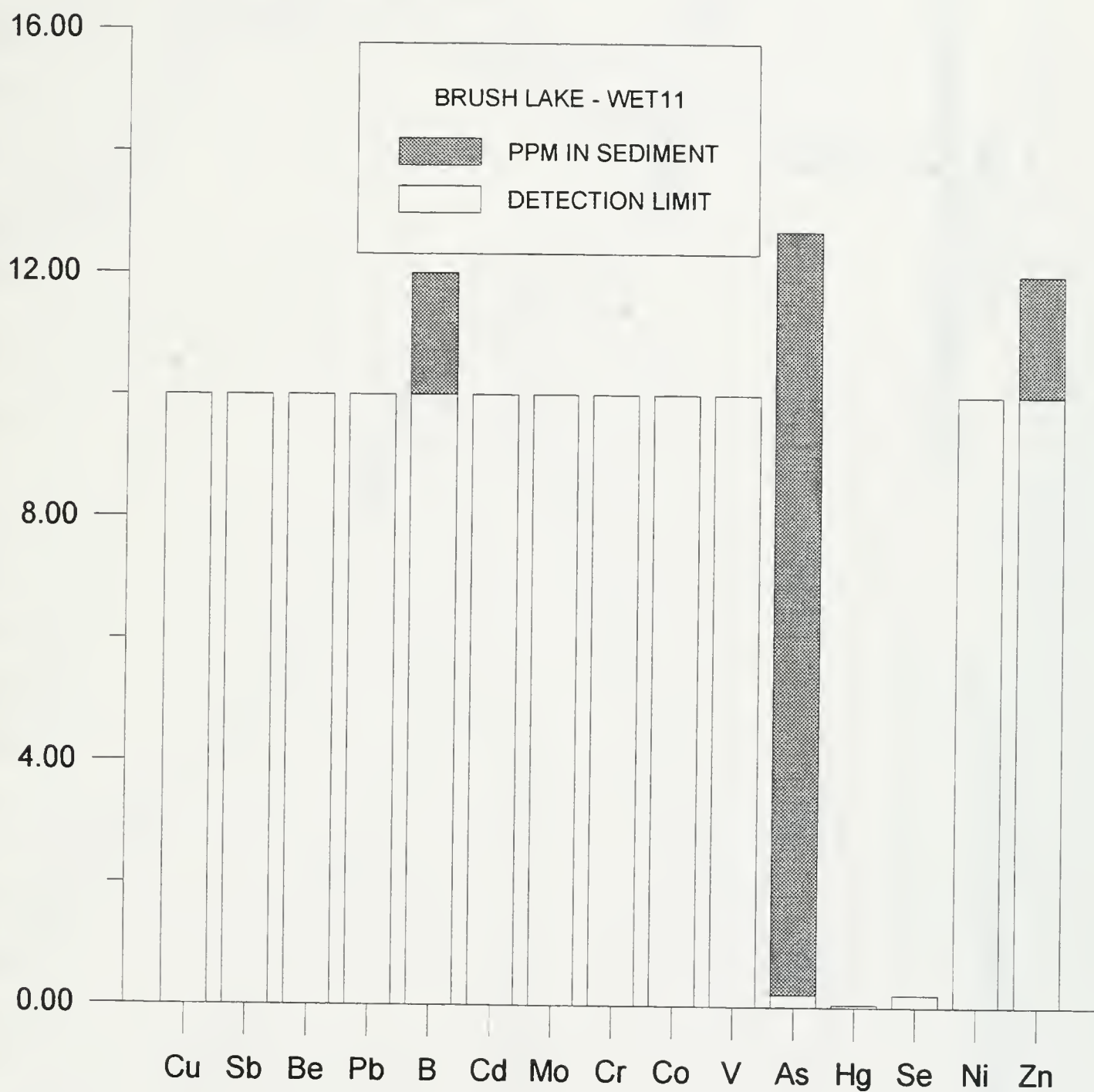


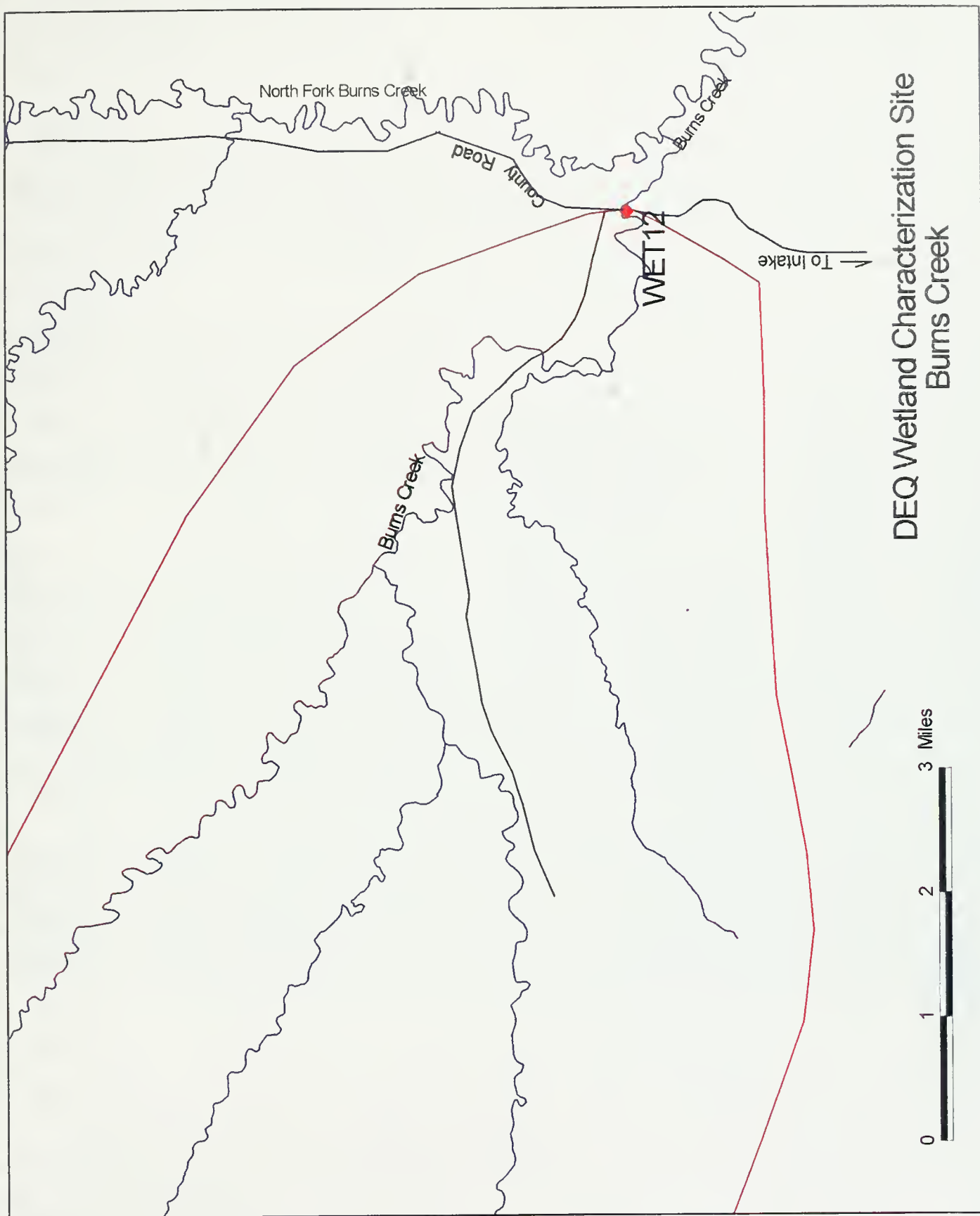
Inches Precipitation



Concentrations in Milligrams per liter







Wetland: BURNS CREEK WETLAND

Site Code: WET12

7.5 Minute Quad: ALLARD RANCH

Lat: 47 24 45

Long: 104 33 35

Mean Annual Precipitation in Inches: 13.00

Mean Annual Potential Evaporation (Penman) in Inches: 39.00

'Net Precipitation' in Inches: -26.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 20 acres

Area of contributing drainage basin: 2400 acres

Mapped elevation of wetland surface: 2170 ft

Maximum elevation within drainage basin: 2732 ft

Net relief of contributing basin: 562 ft

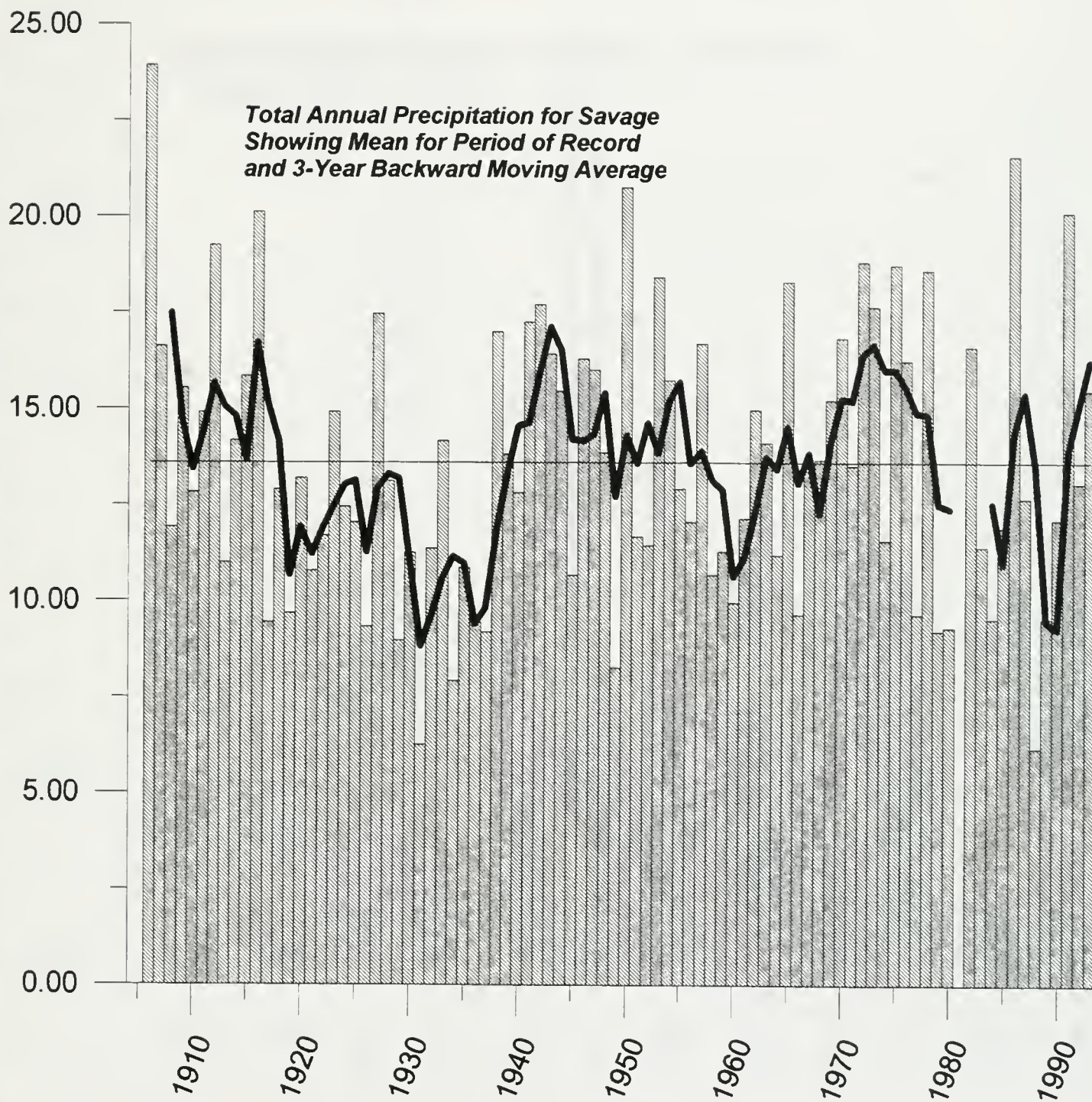
COE Hydrogeomorphic class: RIVERINE

Primary surficial geologic unit 110ALVM

Primary bedrock geologic unit 125FRUN

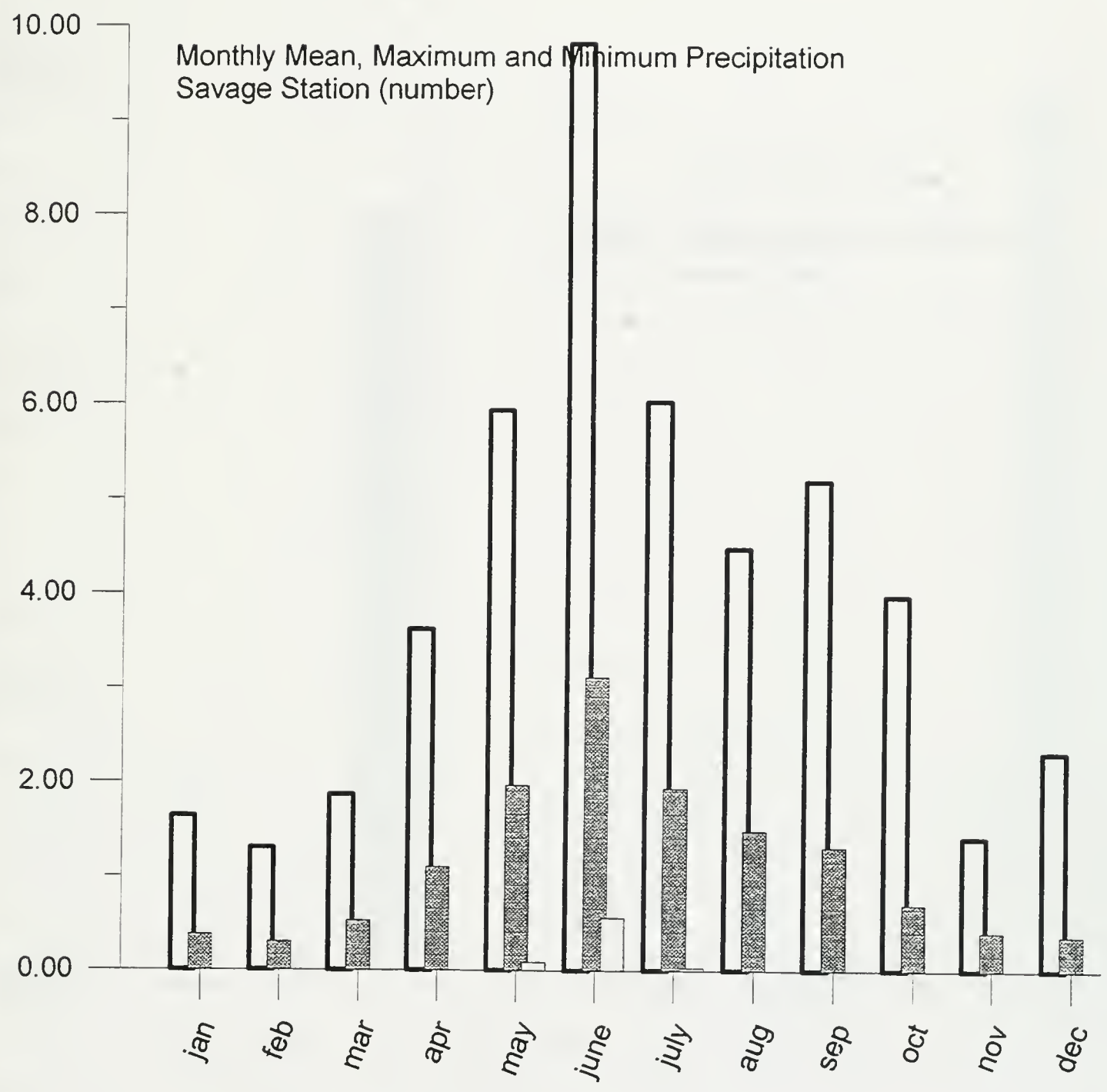
Annual Precipitation in Inches

*Total Annual Precipitation for Savage
Showing Mean for Period of Record
and 3-Year Backward Moving Average*

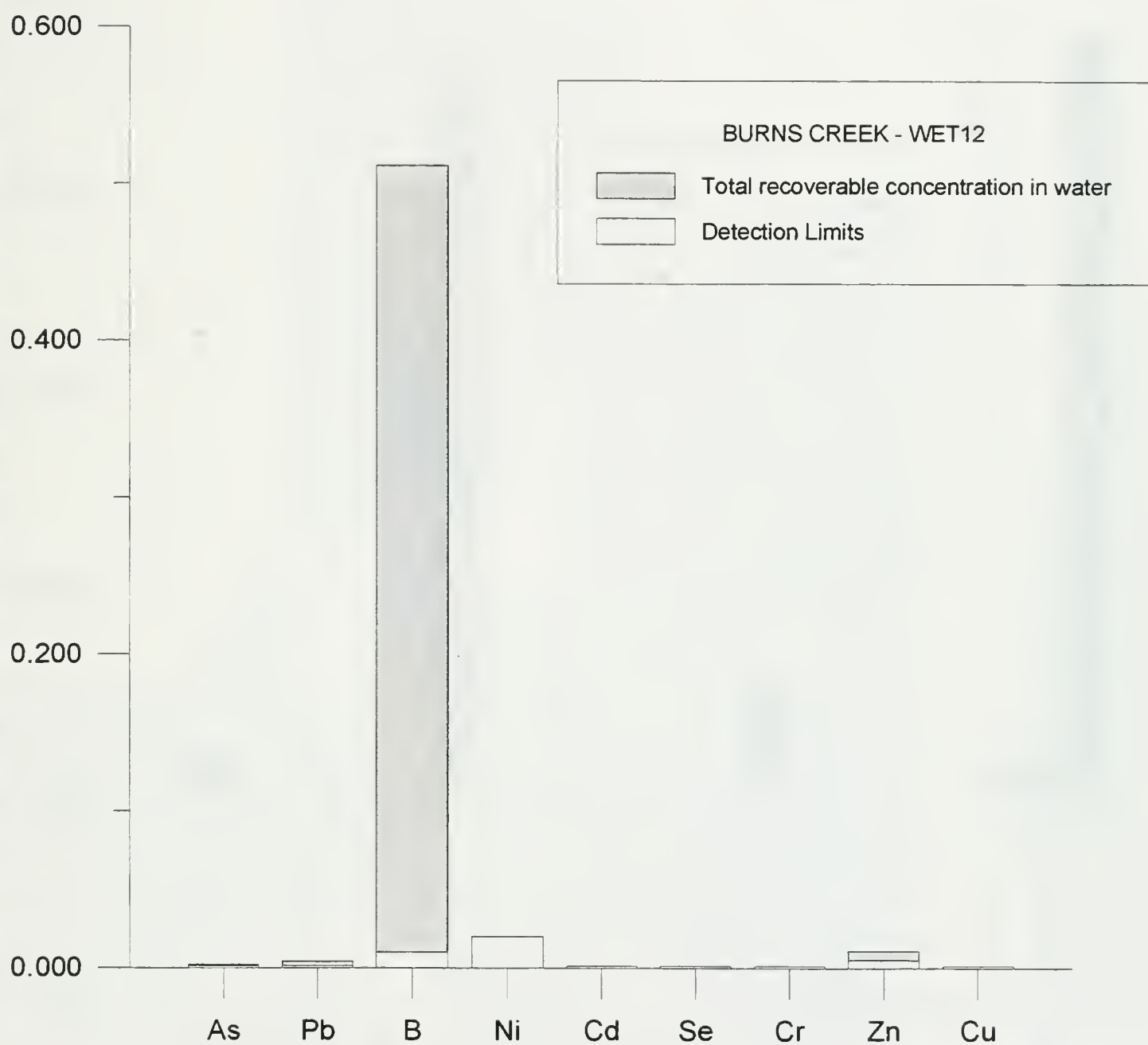


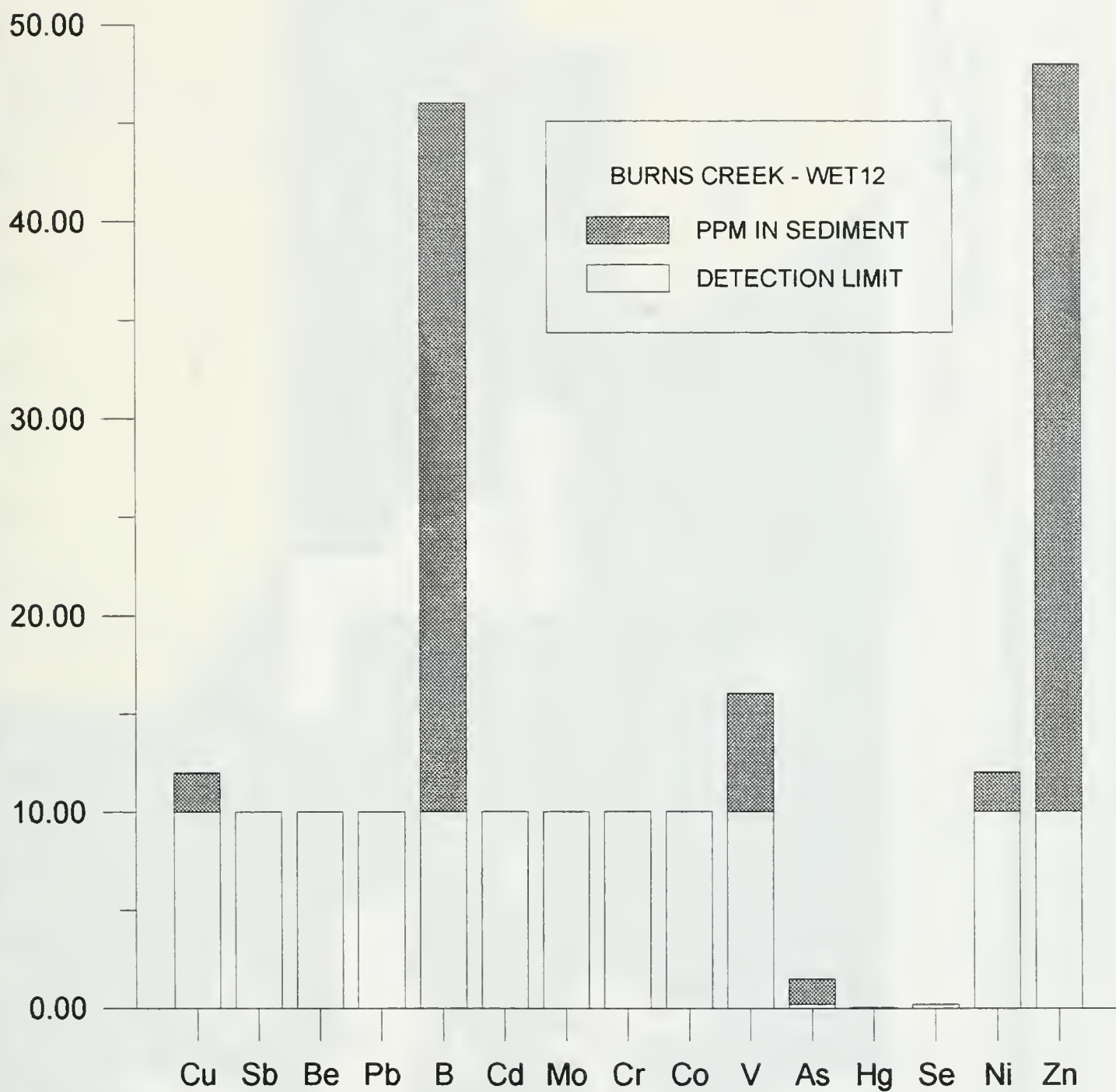
Inches Precipitation

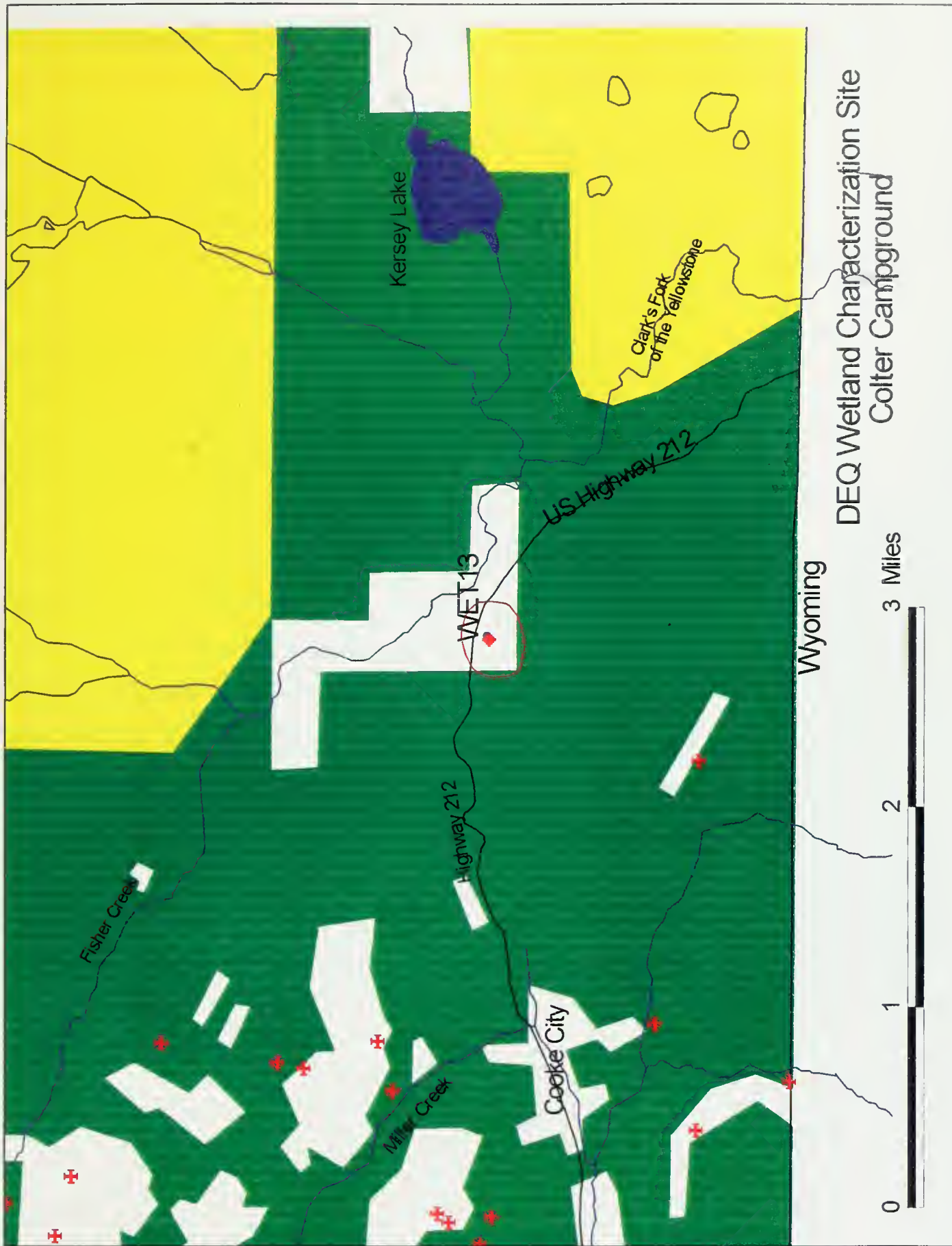
Monthly Mean, Maximum and Minimum Precipitation
Savage Station (number)



Concentrations in Milligrams per liter







Wetland: COLTER CAMPGROUND WETLAND

Site Code: WET13

7.5 Minute Quad: COOKE CITY

Lat: 45 1 30

Long: 109 53 10

Mean Annual Precipitation in Inches: 70.00

Mean Annual Potential Evaporation (Penman) in Inches: 26.00

'Net Precipitation' in Inches: 44.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 1 acres

Area of contributing drainage basin: 60 acres

Mapped elevation of wetland surface: 8015 ft

Maximum elevation within drainage basin: 8285 ft

Net relief of contributing basin: 270 ft

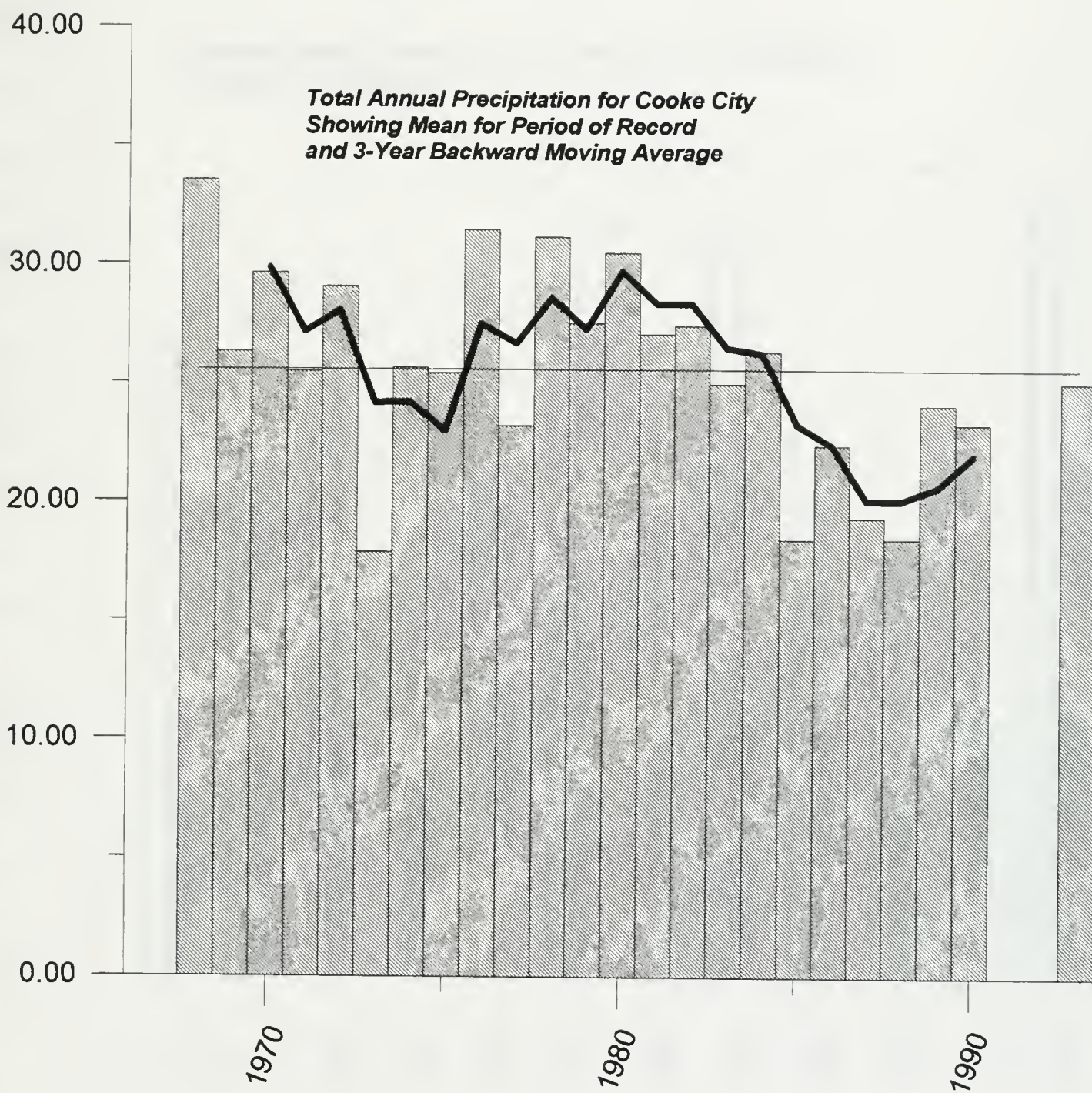
COE Hydrogeomorphic class: DEPRESSIONAL

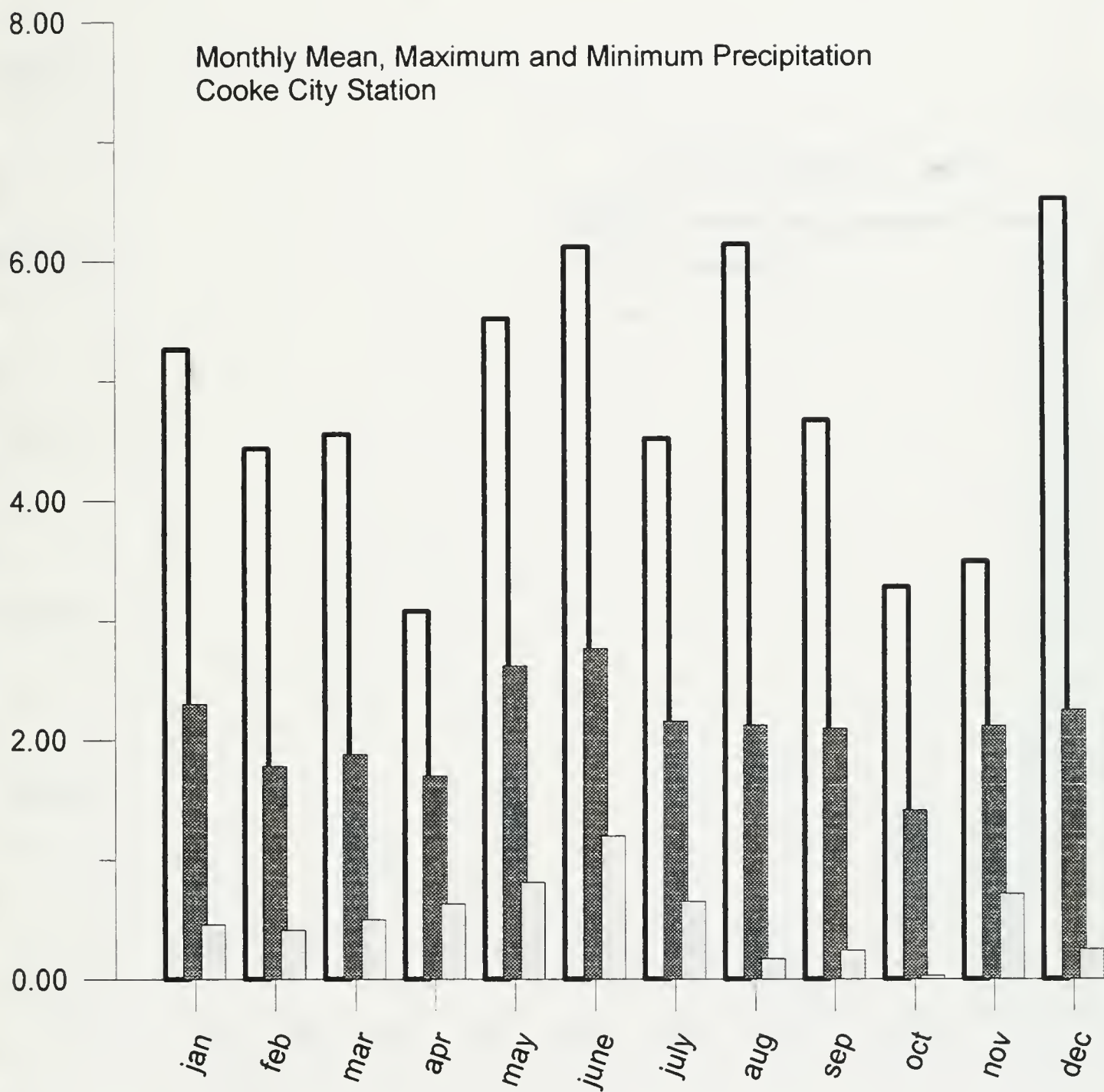
Primary surficial geologic unit 112DRFT

Primary bedrock geologic unit 400PCMB

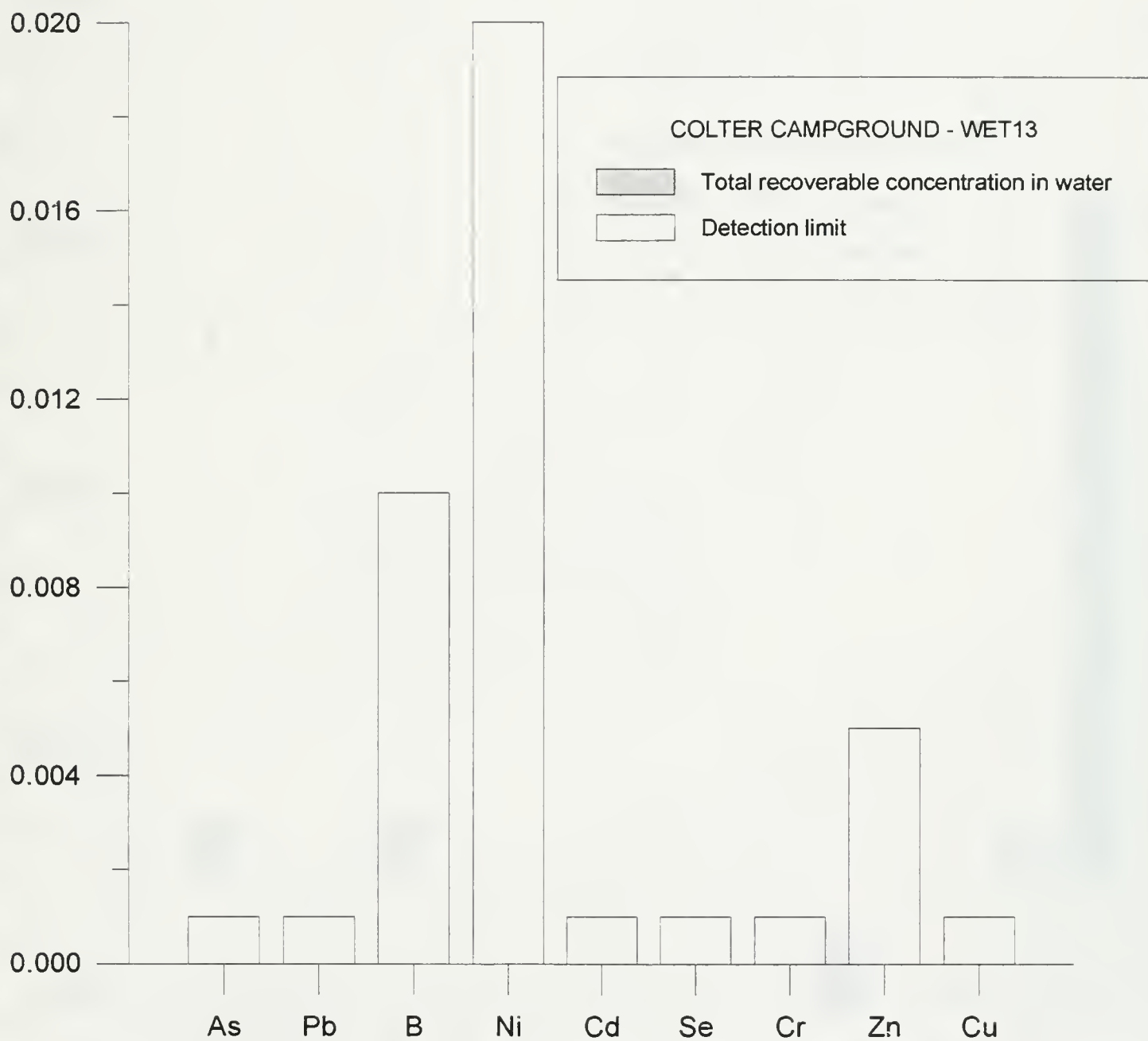
Annual Precipitation in Inches

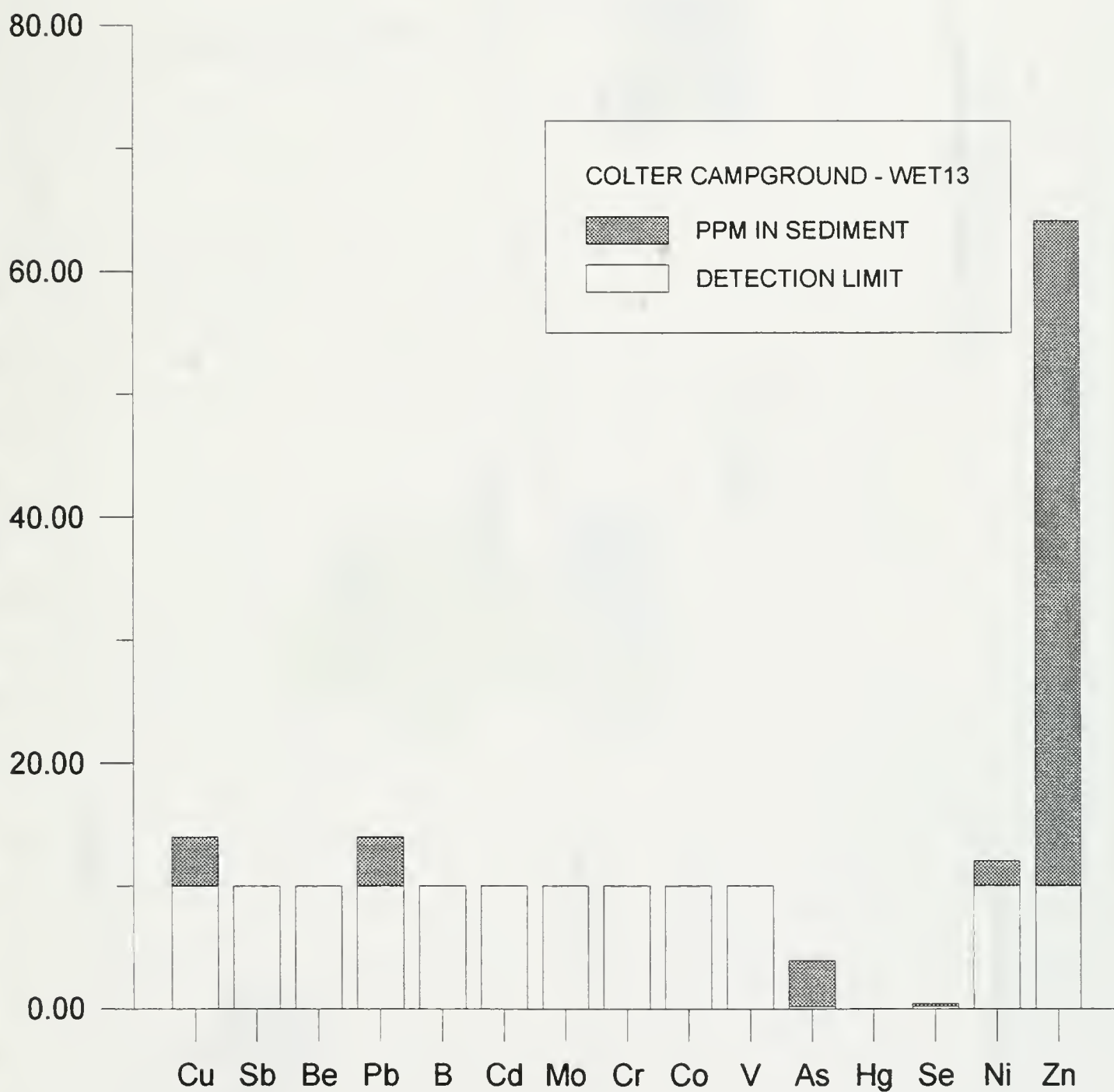
**Total Annual Precipitation for Cooke City
Showing Mean for Period of Record
and 3-Year Backward Moving Average**

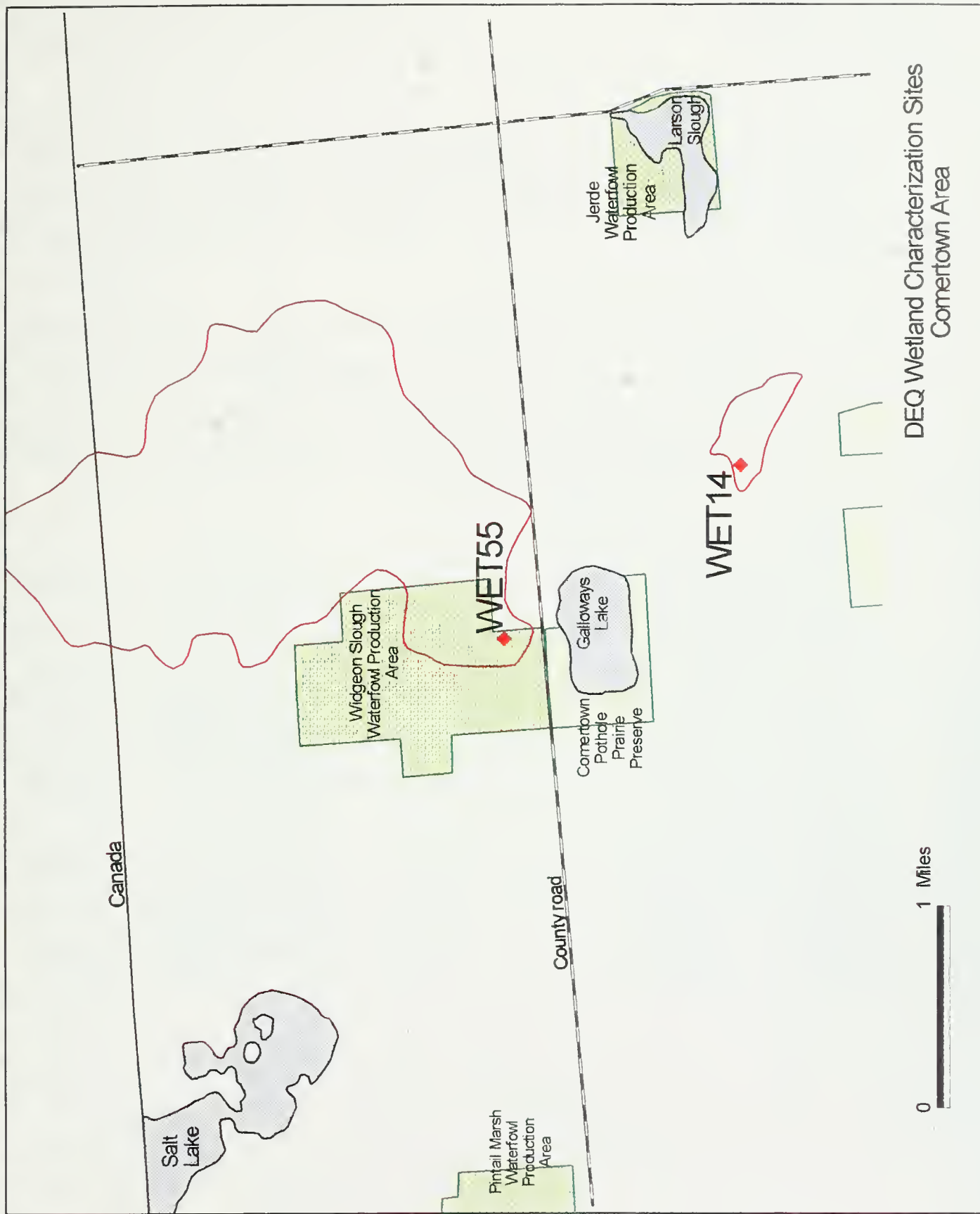




Concentrations in Milligrams per liter







Wetland: COMERTOWN PRESERVE

Site Code: WET14

7.5 Minute Quad: LONE TREE LAKE

Lat: 48 57 15
Long: 104 13 40

Mean Annual Precipitation in Inches:	15.00
Mean Annual Potential Evaporation (Penman) in Inches:	35.00
'Net Precipitation' in Inches:	-20.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

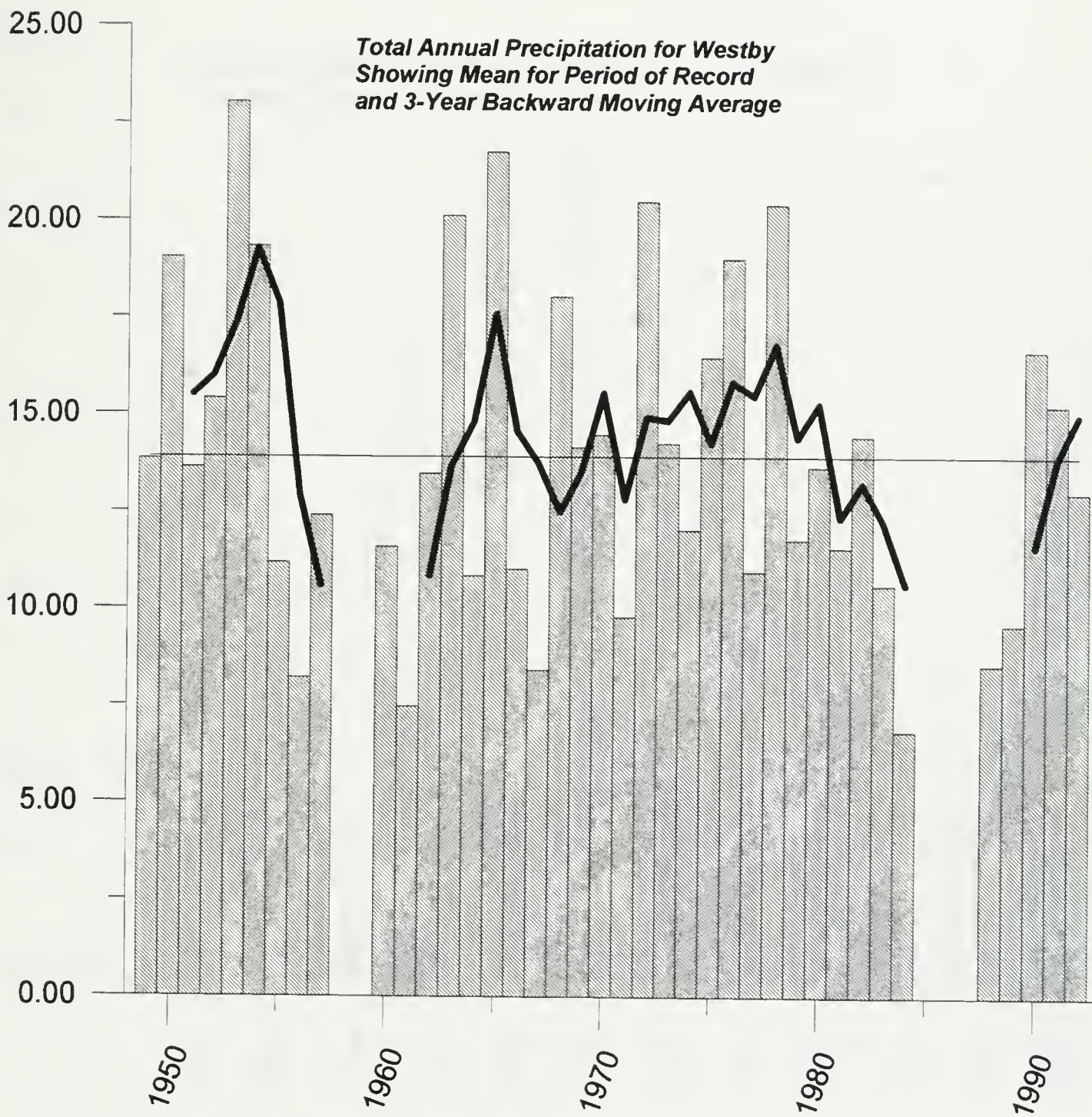
Site is not known to be artificially impounded.

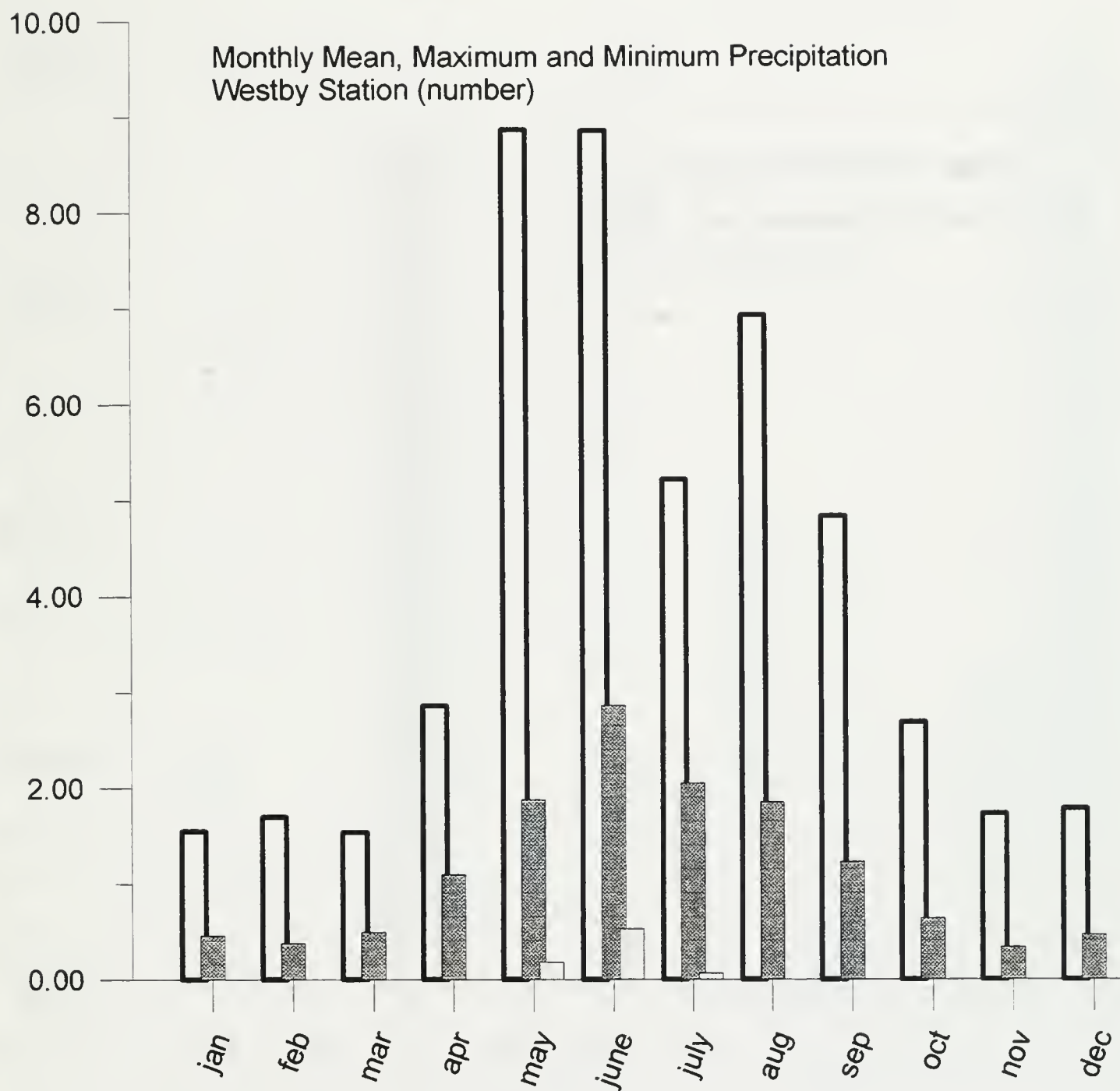
Site does not have known significant water imports.

Mapped area of wetland:	27 acres
Area of contributing drainage basin:	75 acres
Mapped elevation of wetland surface:	2169 ft
Maximum elevation within drainage basin:	2320 ft
Net relief of contributing basin:	151 ft

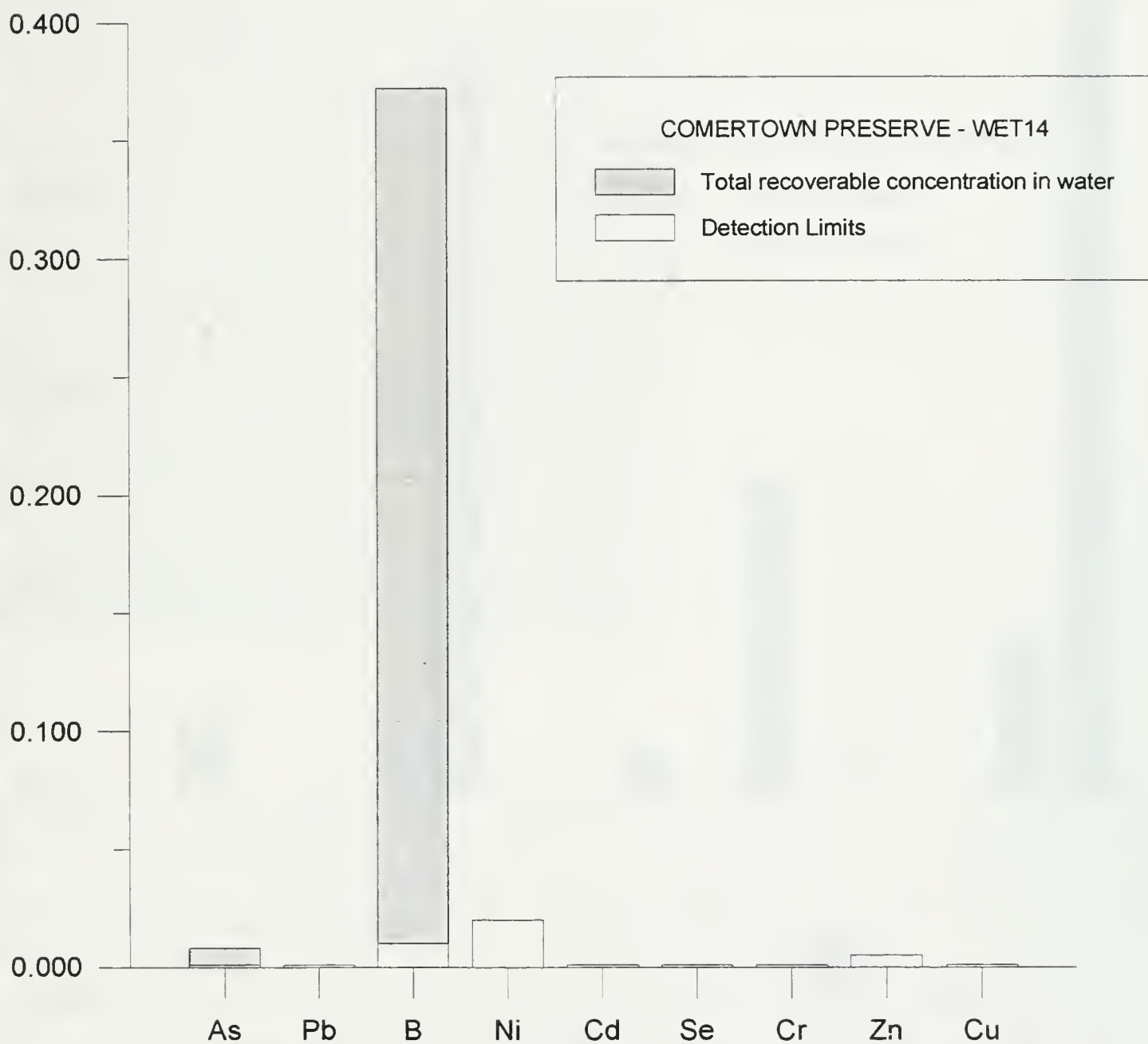
COE Hydrogeomorphic class:	DEPRESSIONAL
Primary surficial geologic unit	112TILL
Primary bedrock geologic unit	125FRUN

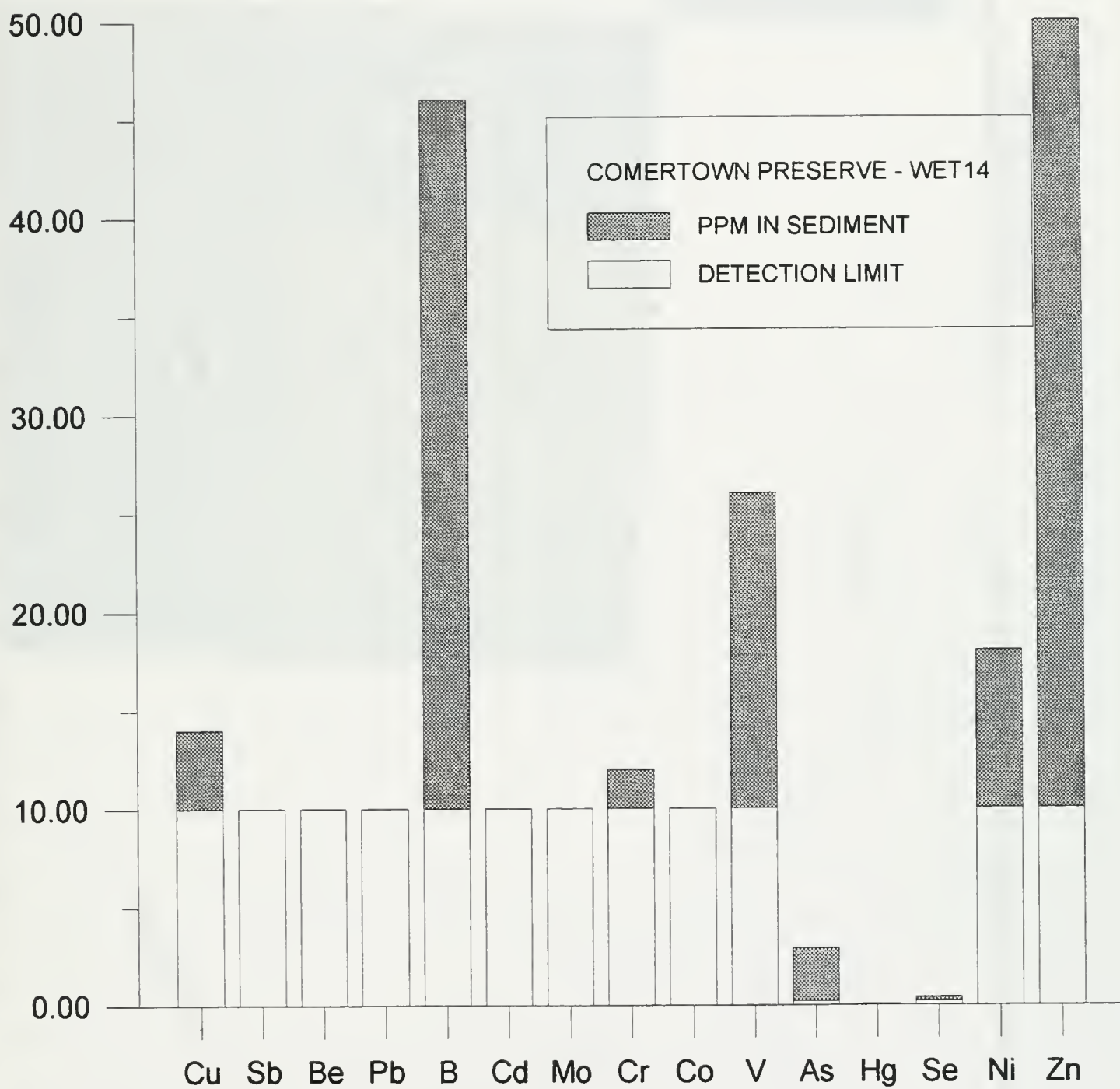
Annual Precipitation in Inches

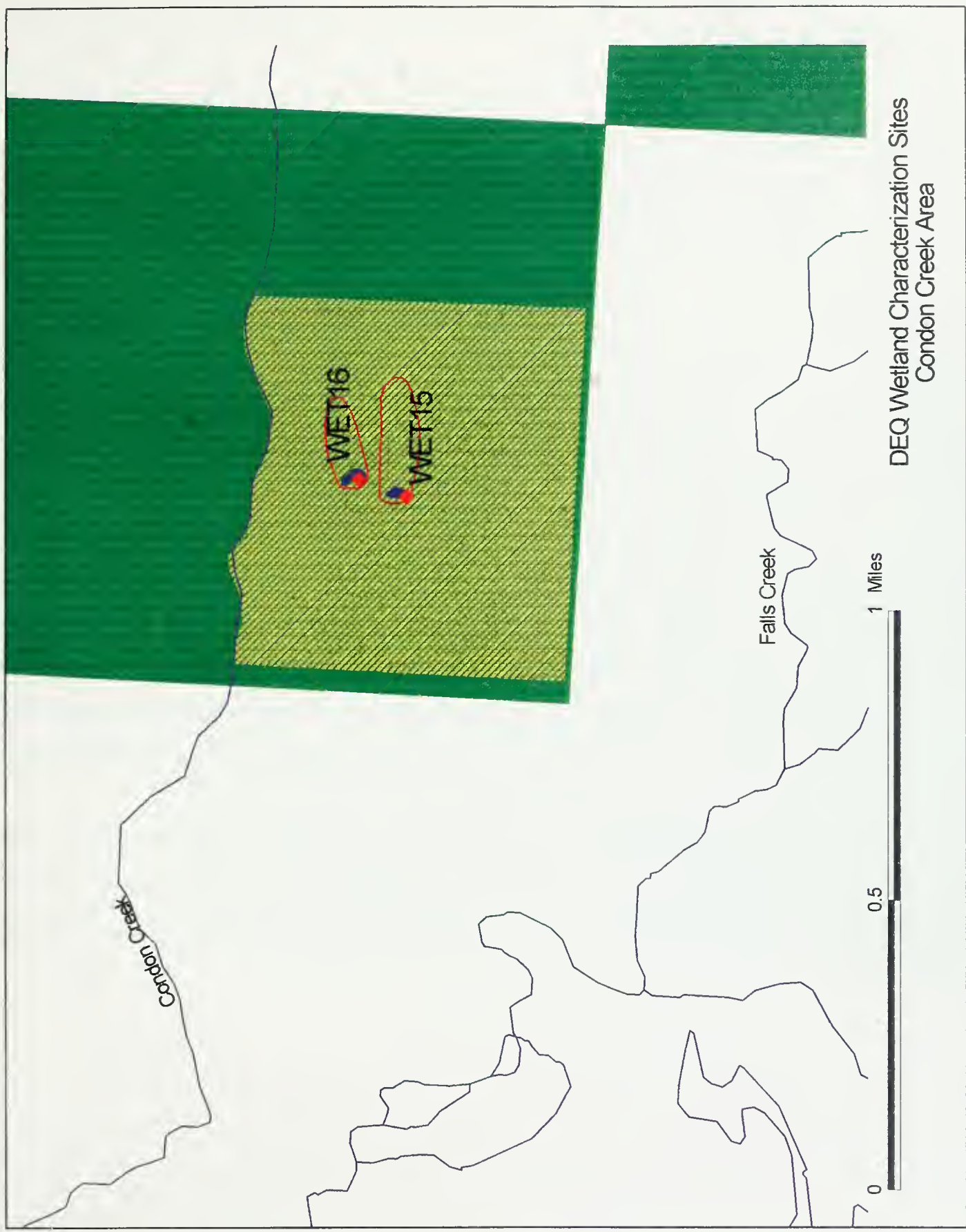




Concentrations in Milligrams per liter







DEQ Wetland Characterization Sites
Condon Creek Area

Wetland: CONDON CREEK PROPOSED RNA POND #1

Site Code: WET15

7.5 Minute Quad: CONDON

Lat: 47 34 33

Long: 113 42 10

Mean Annual Precipitation in Inches: 25.00

Mean Annual Potential Evaporation (Penman) in Inches: 33.00

'Net Precipitation' in Inches: -8.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 0 acres

Area of contributing drainage basin: 8 acres

Mapped elevation of wetland surface: 3740 ft

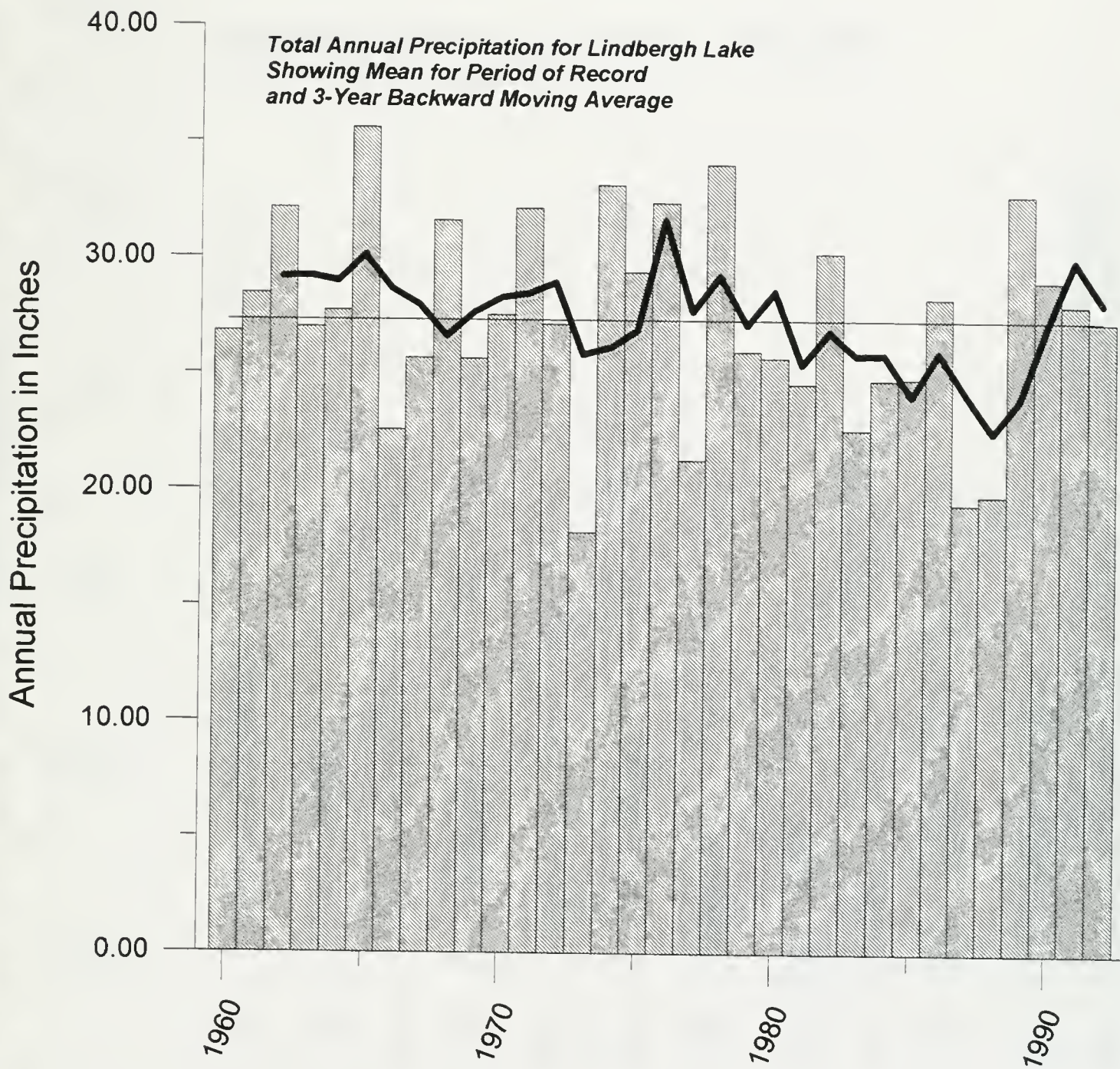
Maximum elevation within drainage basin: 3800 ft

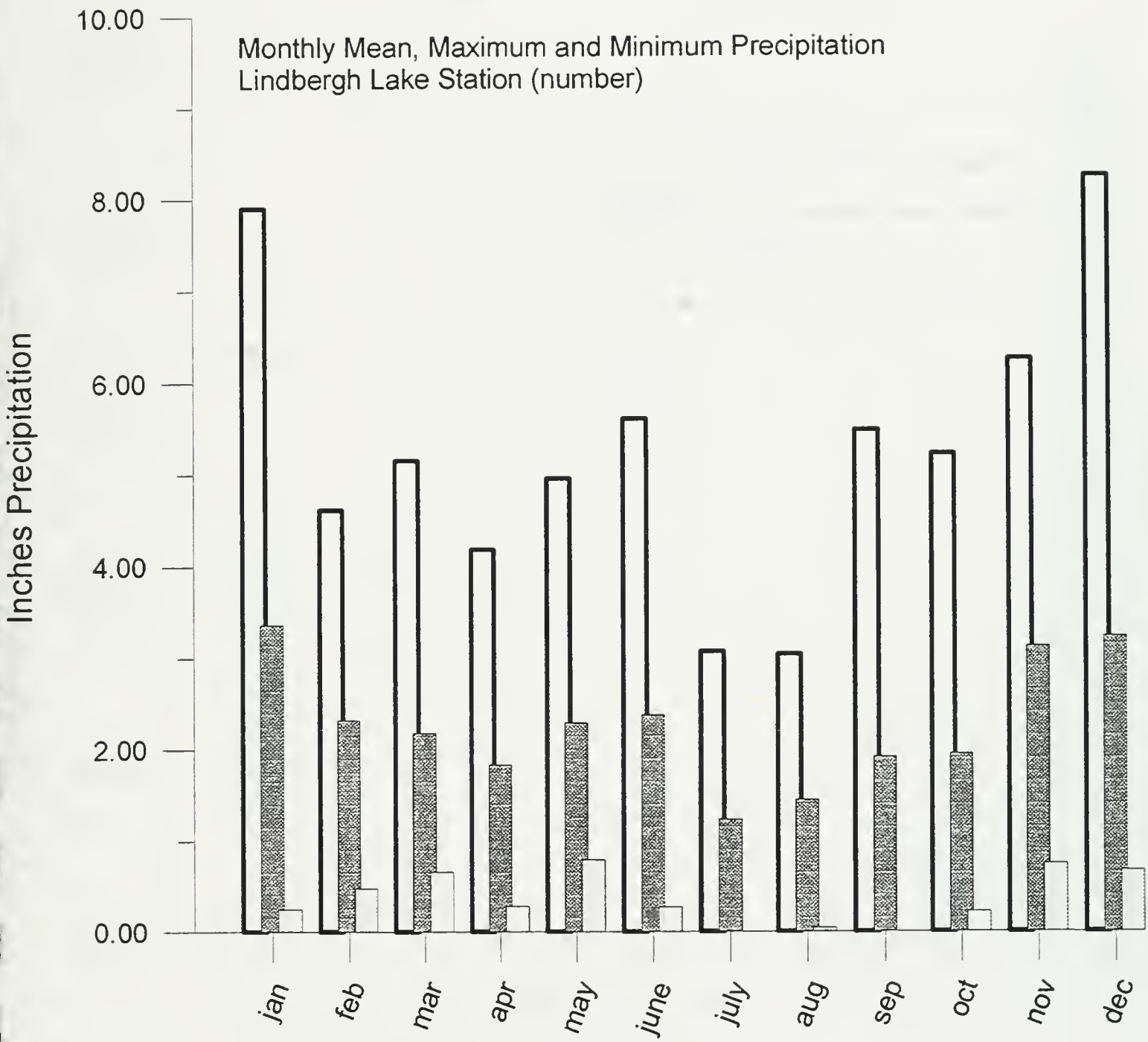
Net relief of contributing basin: 60 ft

COE Hydrogeomorphic class: DEPRESSIONAL

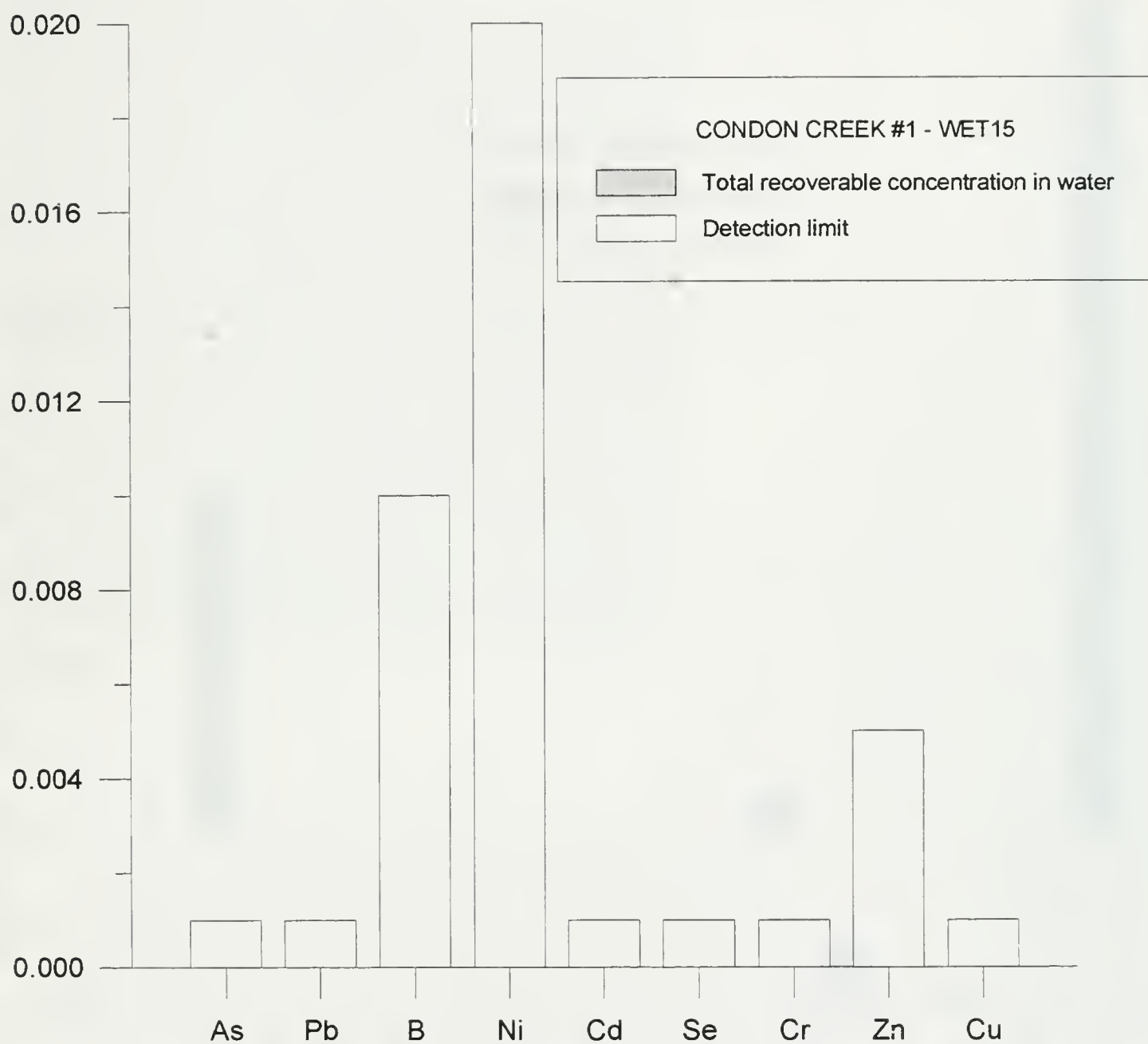
Primary surficial geologic unit 112TILL

Primary bedrock geologic unit 400BELT

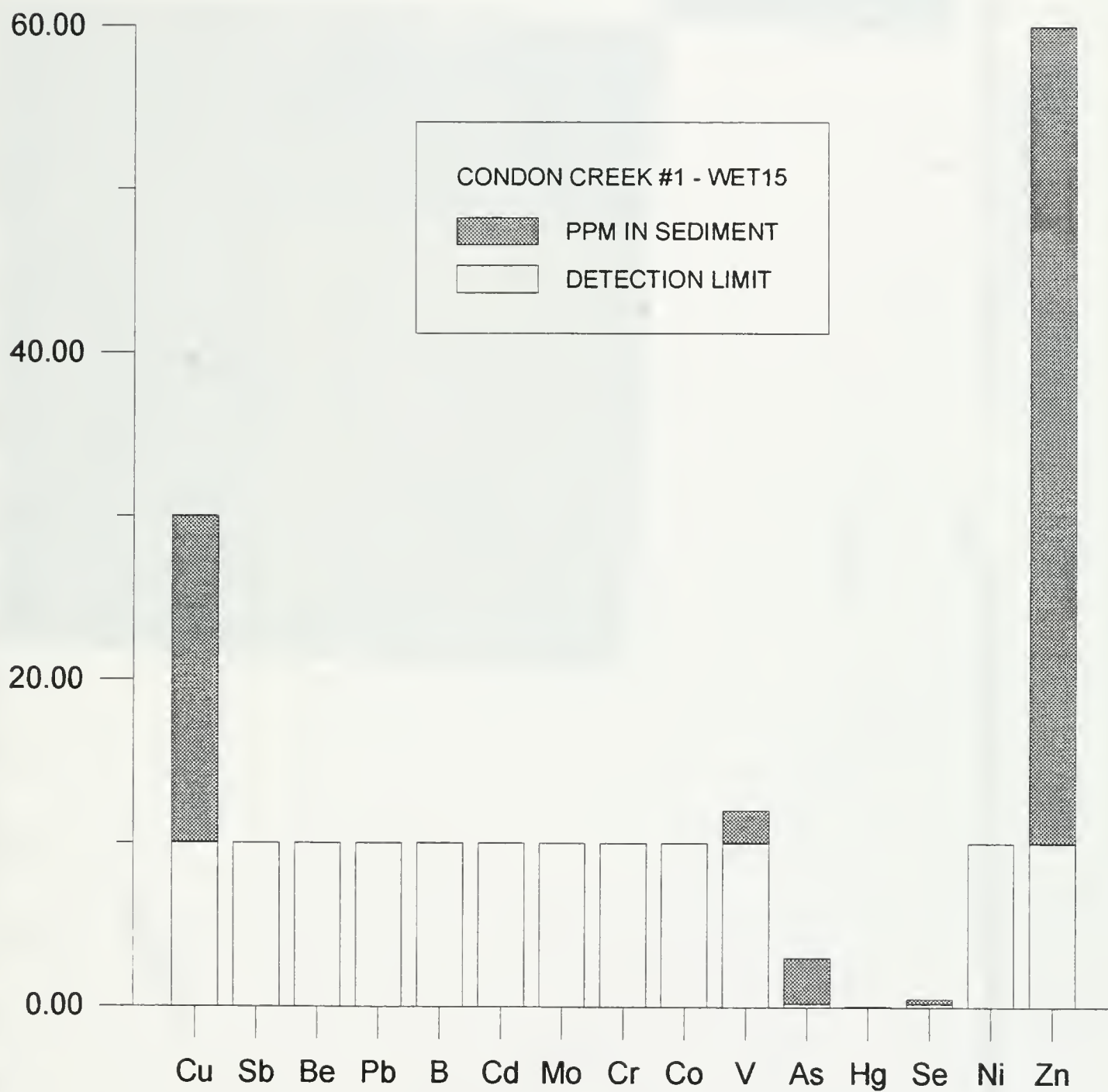




Concentrations in Milligrams per liter



HNO3 - Extractable Sediment Concentrations in PPM





Wetland: CONDON CREEK PROPOSED RNA POND #2

Site Code: WET16

7.5 Minute Quad: CONDON

Lat: 47 34 36

Long: 113 42 10

Mean Annual Precipitation in Inches: 25.00

Mean Annual Potential Evaporation (Penman) in Inches: 33.00

'Net Precipitation' in Inches: -8.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 0 acres

Area of contributing drainage basin: 5 acres

Mapped elevation of wetland surface: 3745 ft

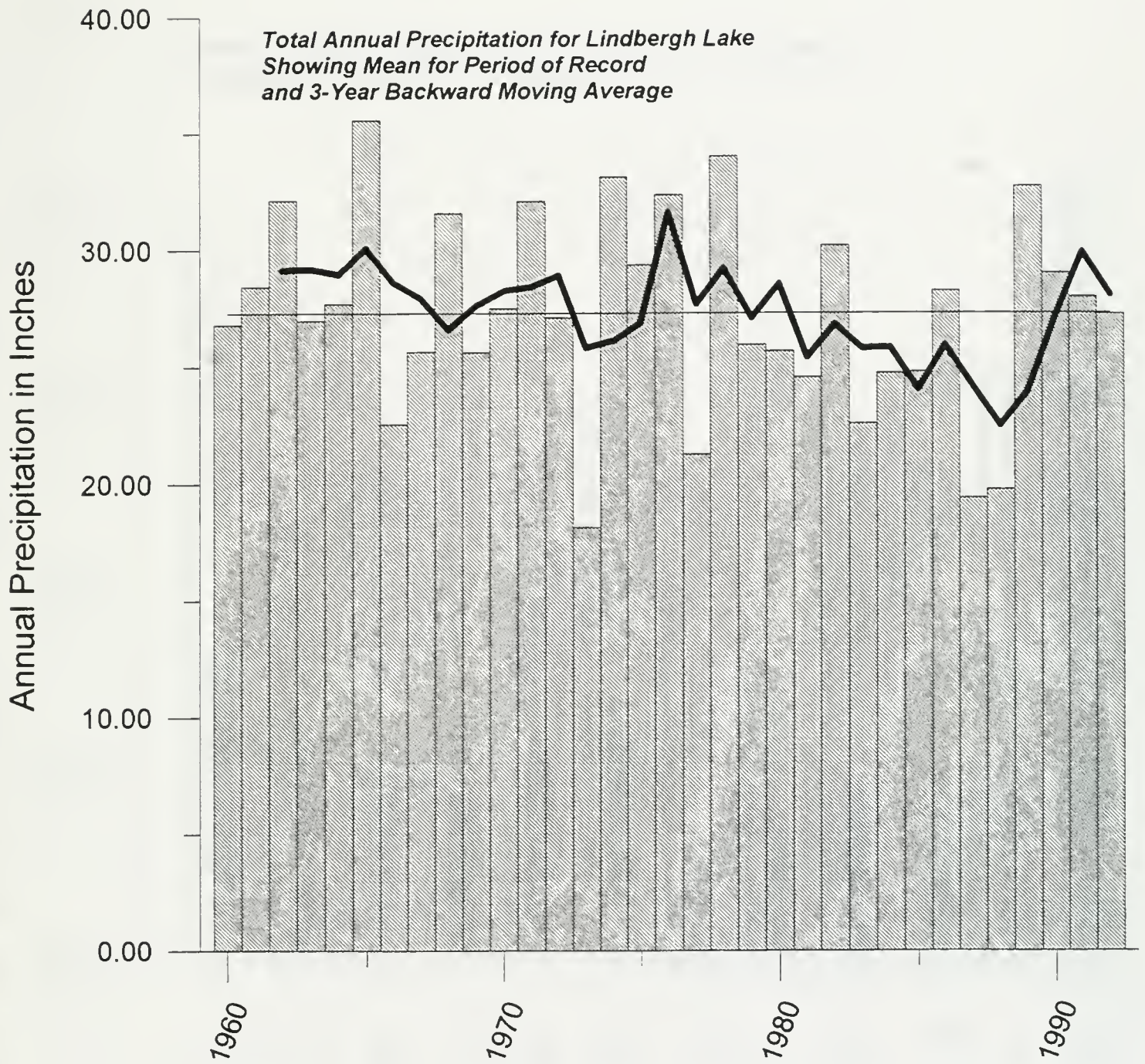
Maximum elevation within drainage basin: 3800 ft

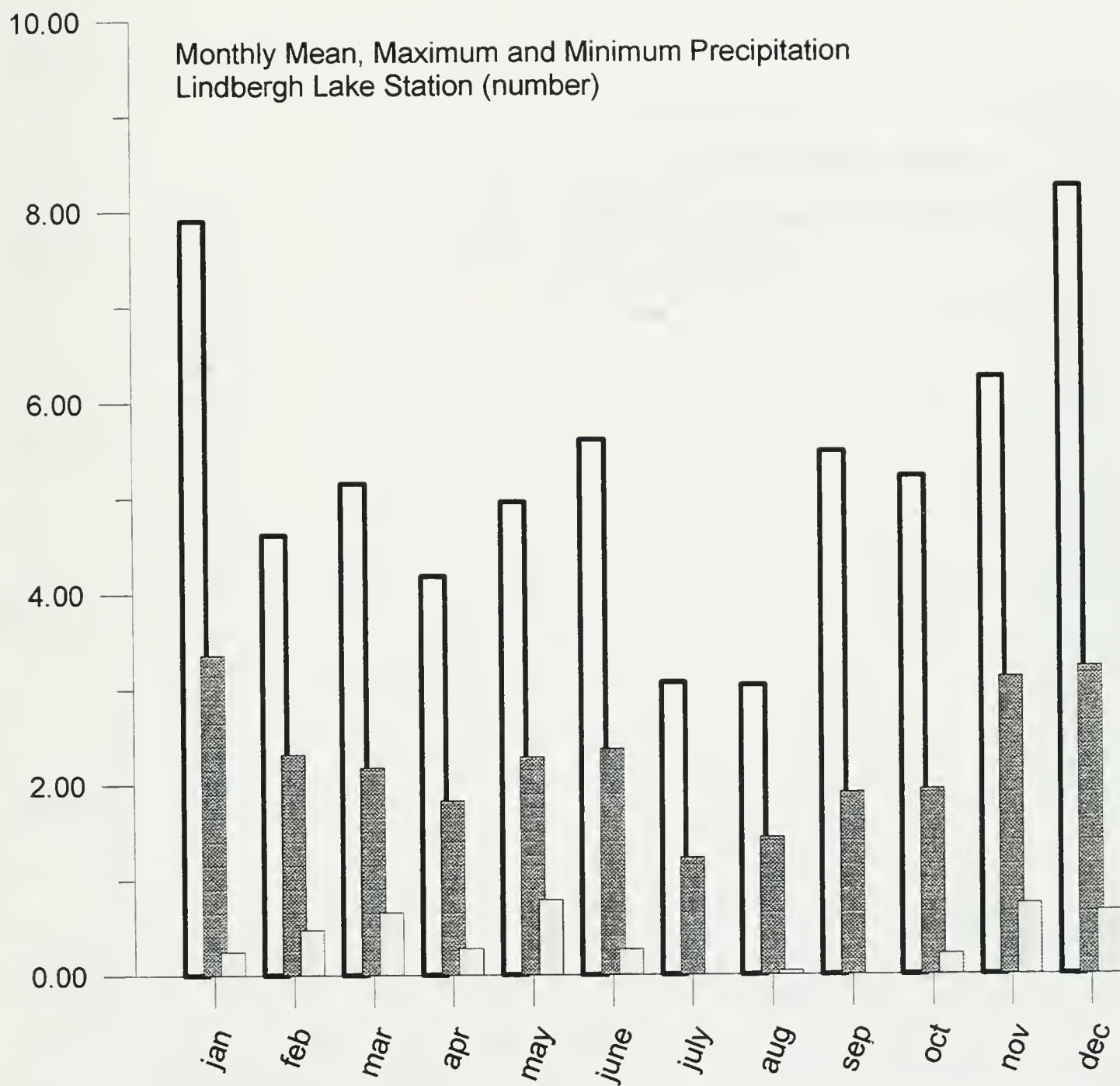
Net relief of contributing basin: 55 ft

COE Hydrogeomorphic class: DEPRESSIONAL

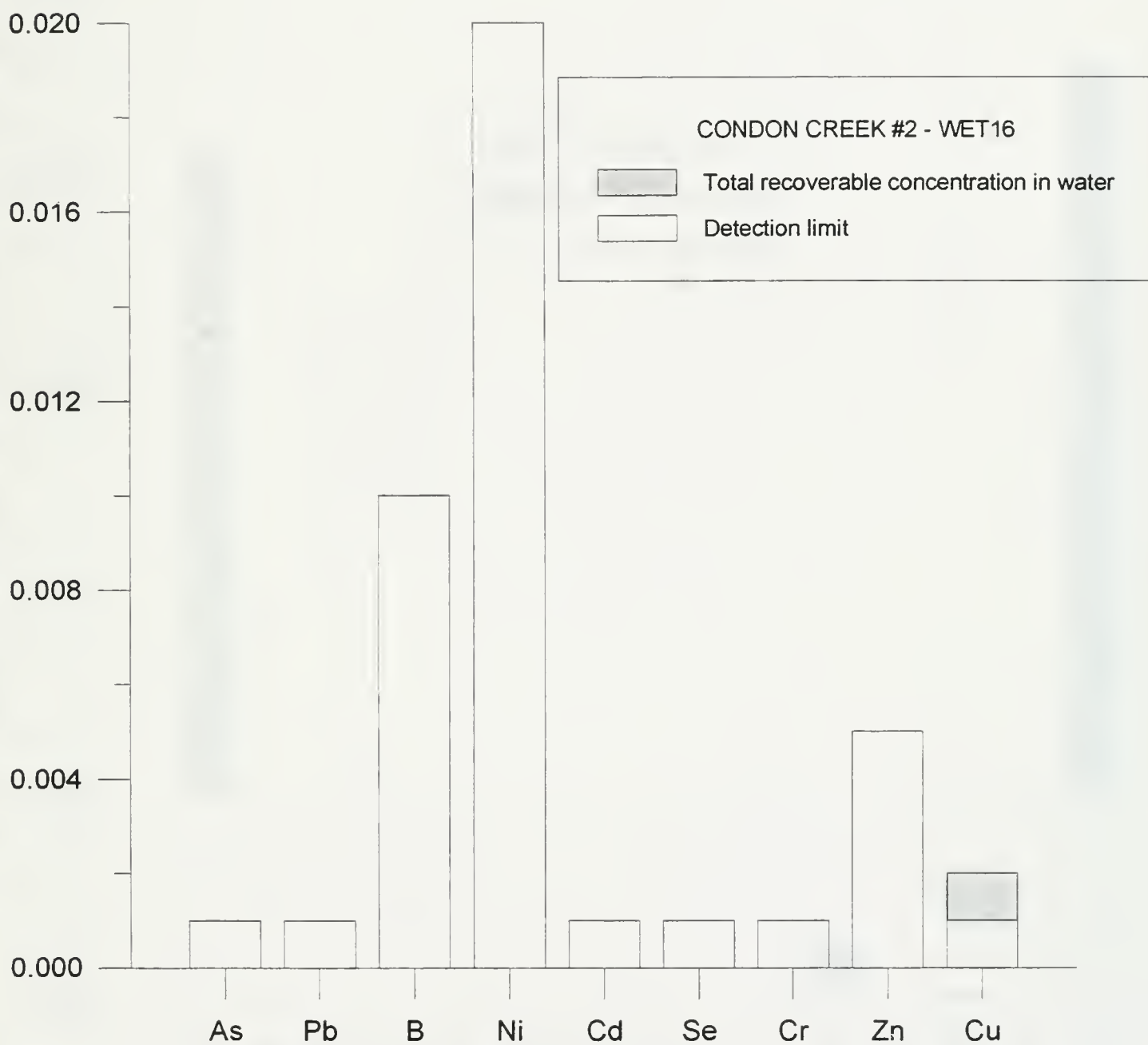
Primary surficial geologic unit 112TILL

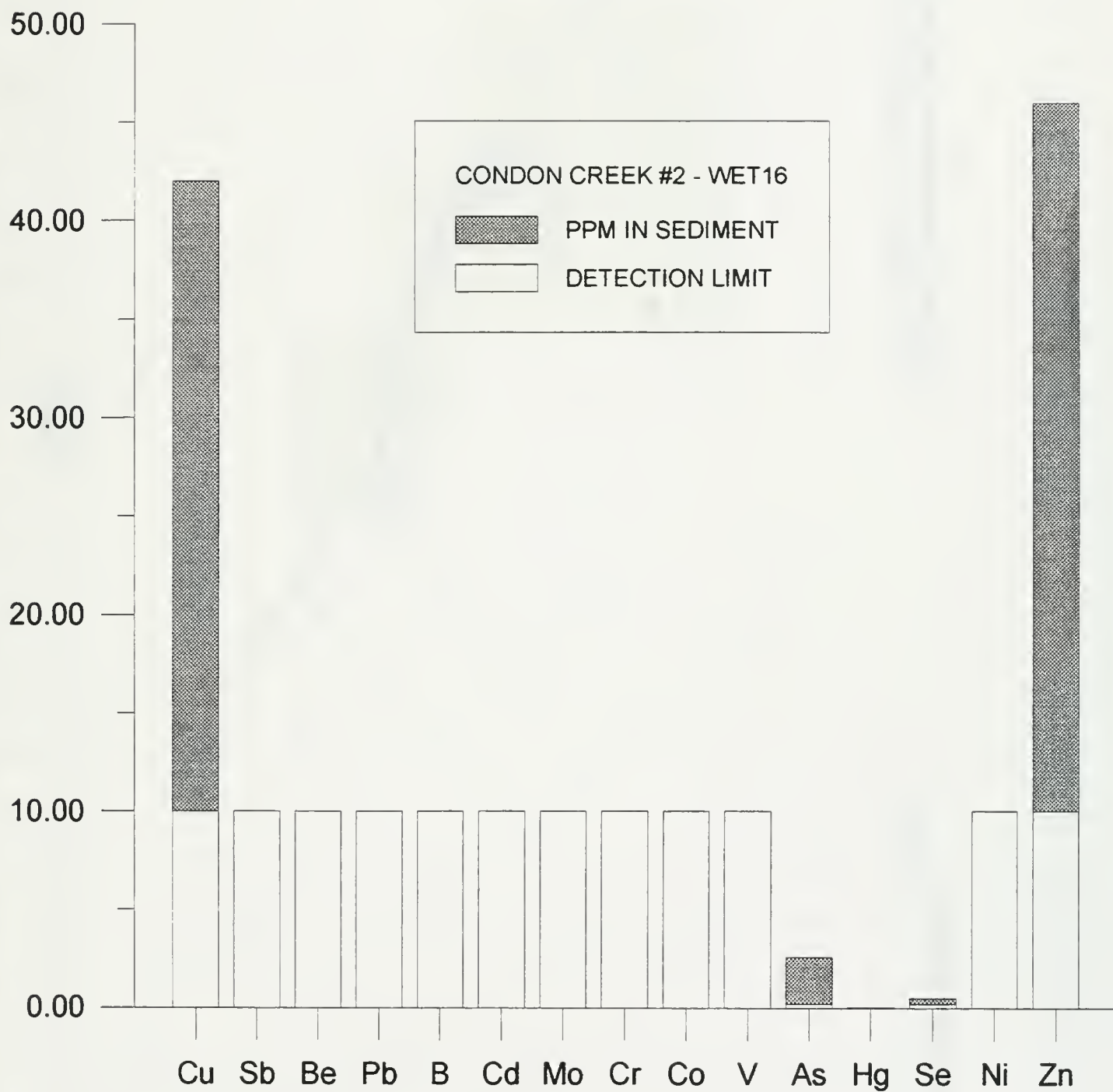
Primary bedrock geologic unit 400BELT

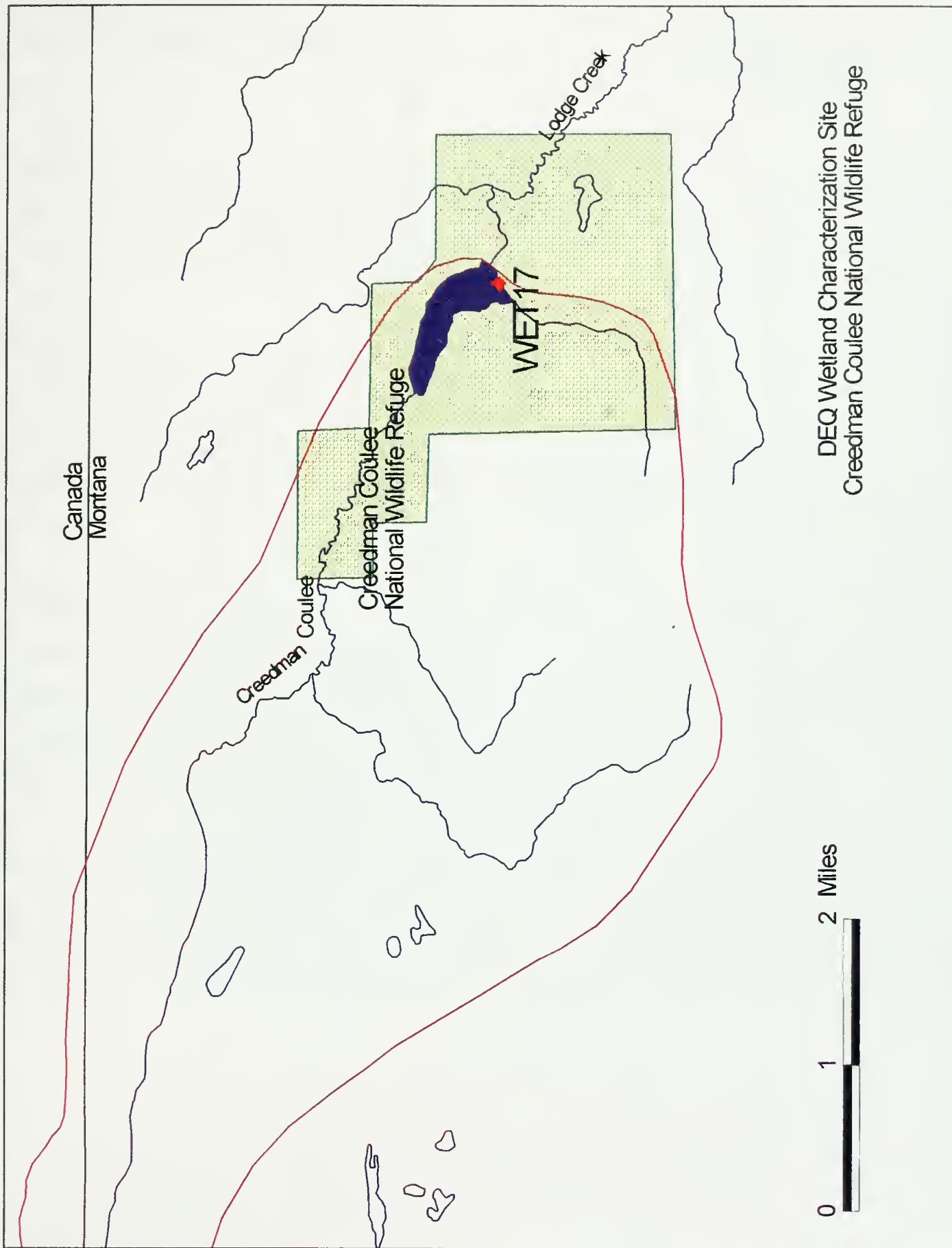




Concentrations in Milligrams per liter







Wetland: CREEDMAN COULEE NWR

Site Code: WET17

7.5 Minute Quad: CREEDMAN COULEE

Lat: 48 57 35

Long: 109 45 5

Mean Annual Precipitation in Inches:	11.00
Mean Annual Potential Evaporation (Penman) in Inches:	36.00
'Net Precipitation' in Inches:	-25.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

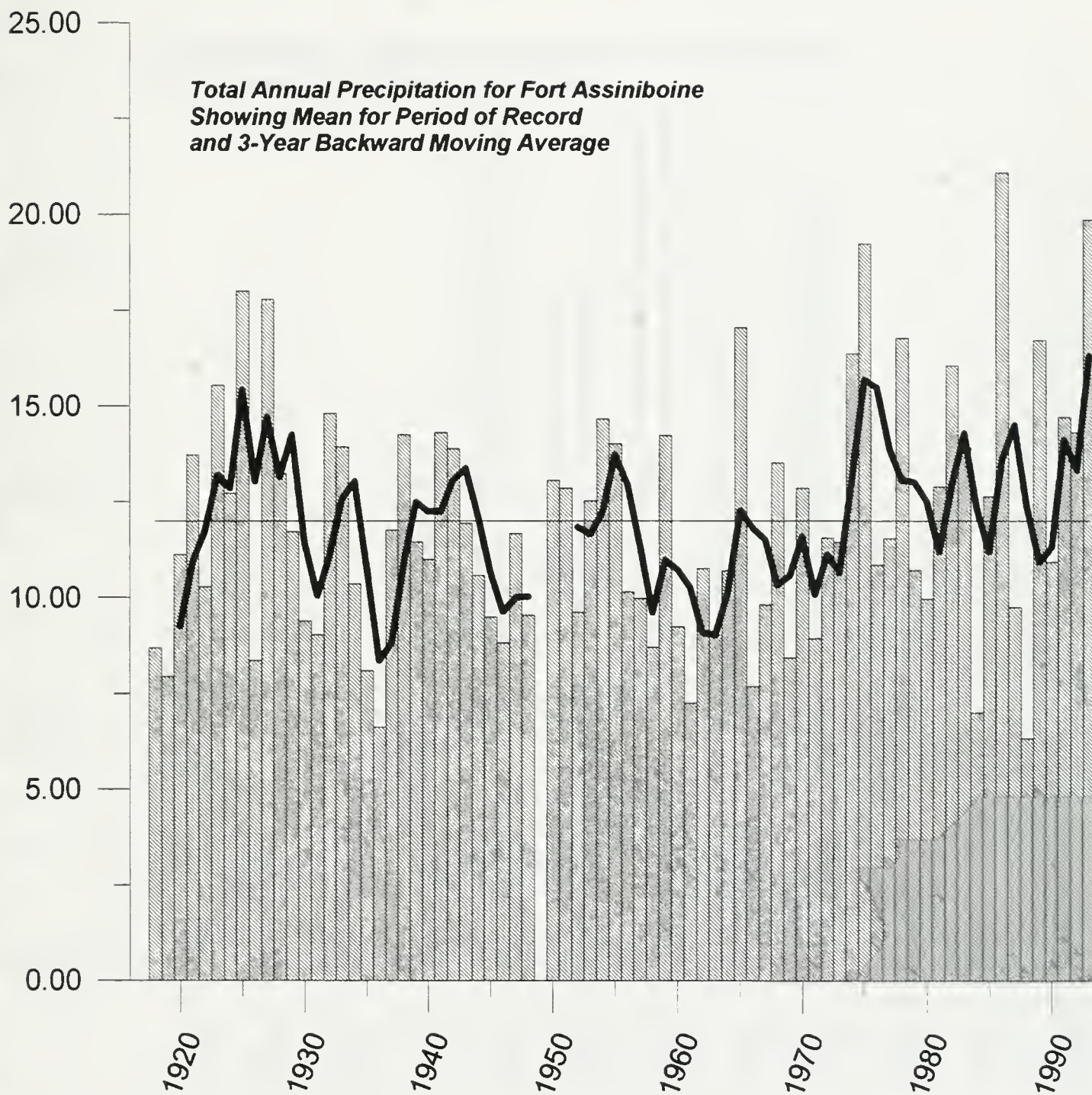
Site is artificially impounded.

Site does not have known significant water imports.

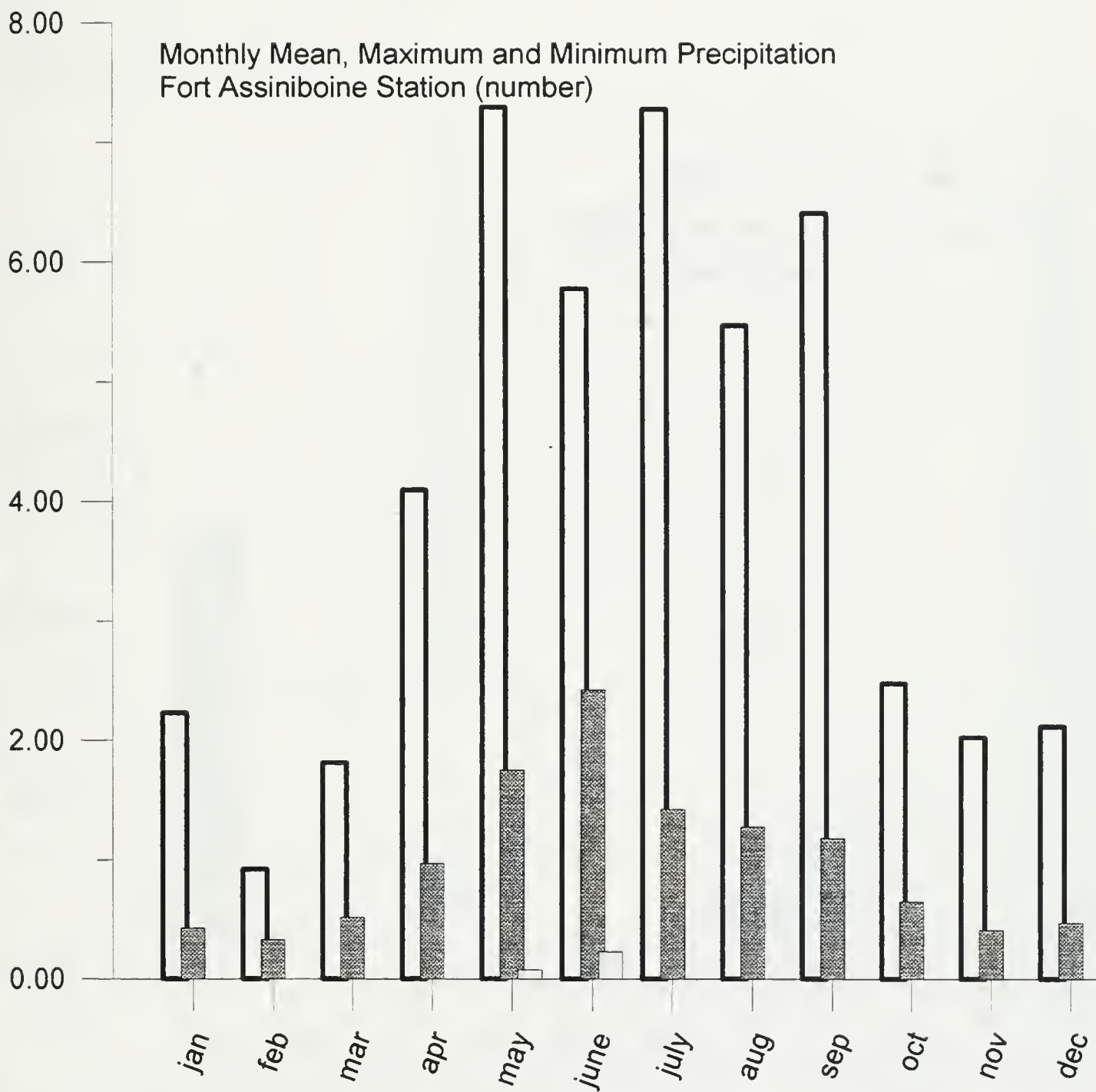
Mapped area of wetland:	135 acres
Area of contributing drainage basin:	13570 acres
Mapped elevation of wetland surface:	2750 ft
Maximum elevation within drainage basin:	3035 ft
Net relief of contributing basin:	285 ft

COE Hydrogeomorphic class:	DEPRESSIONAL
Primary surficial geologic unit	112TILL
Primary bedrock geologic unit	211BRPW

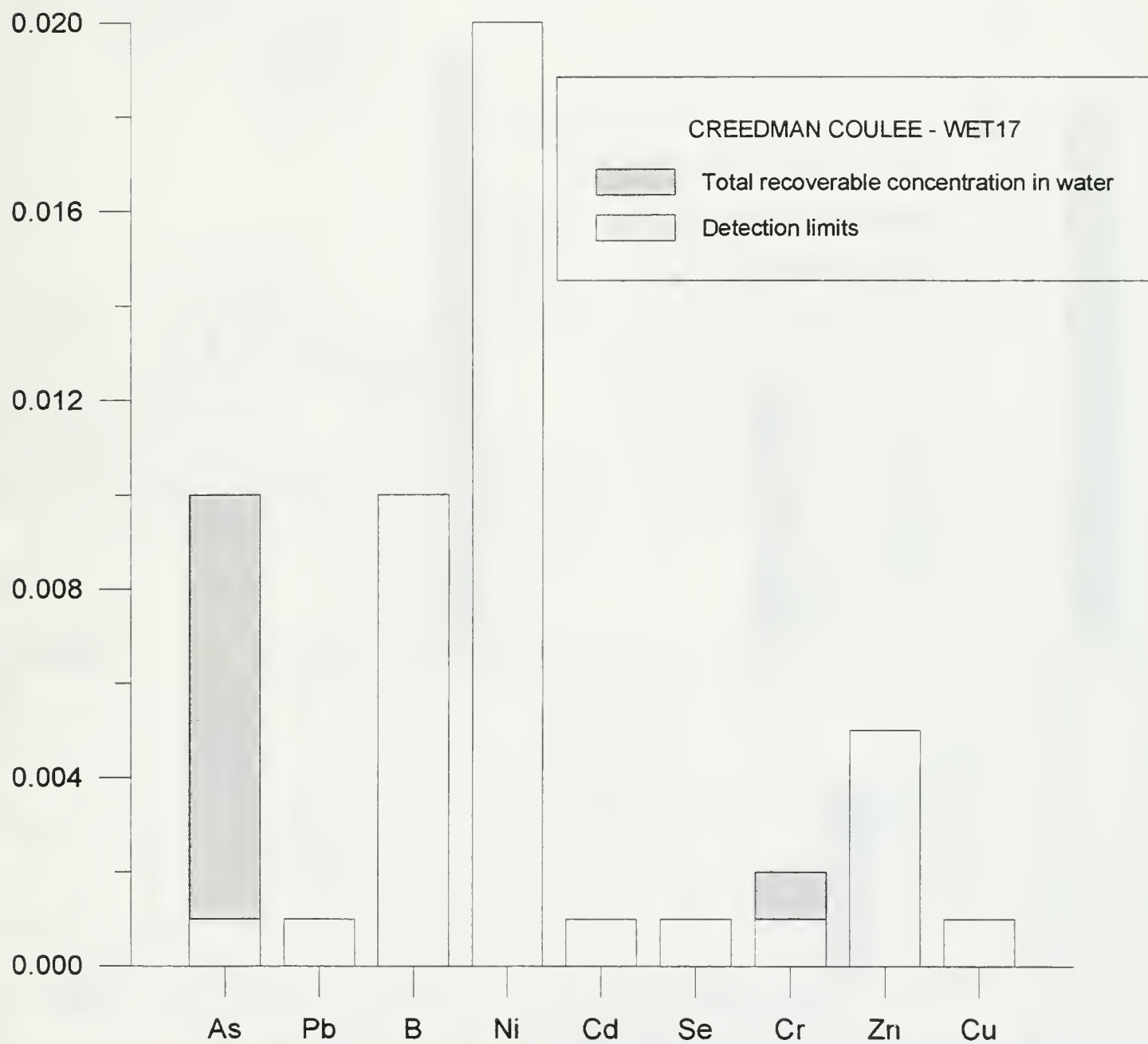
Annual Precipitation in Inches

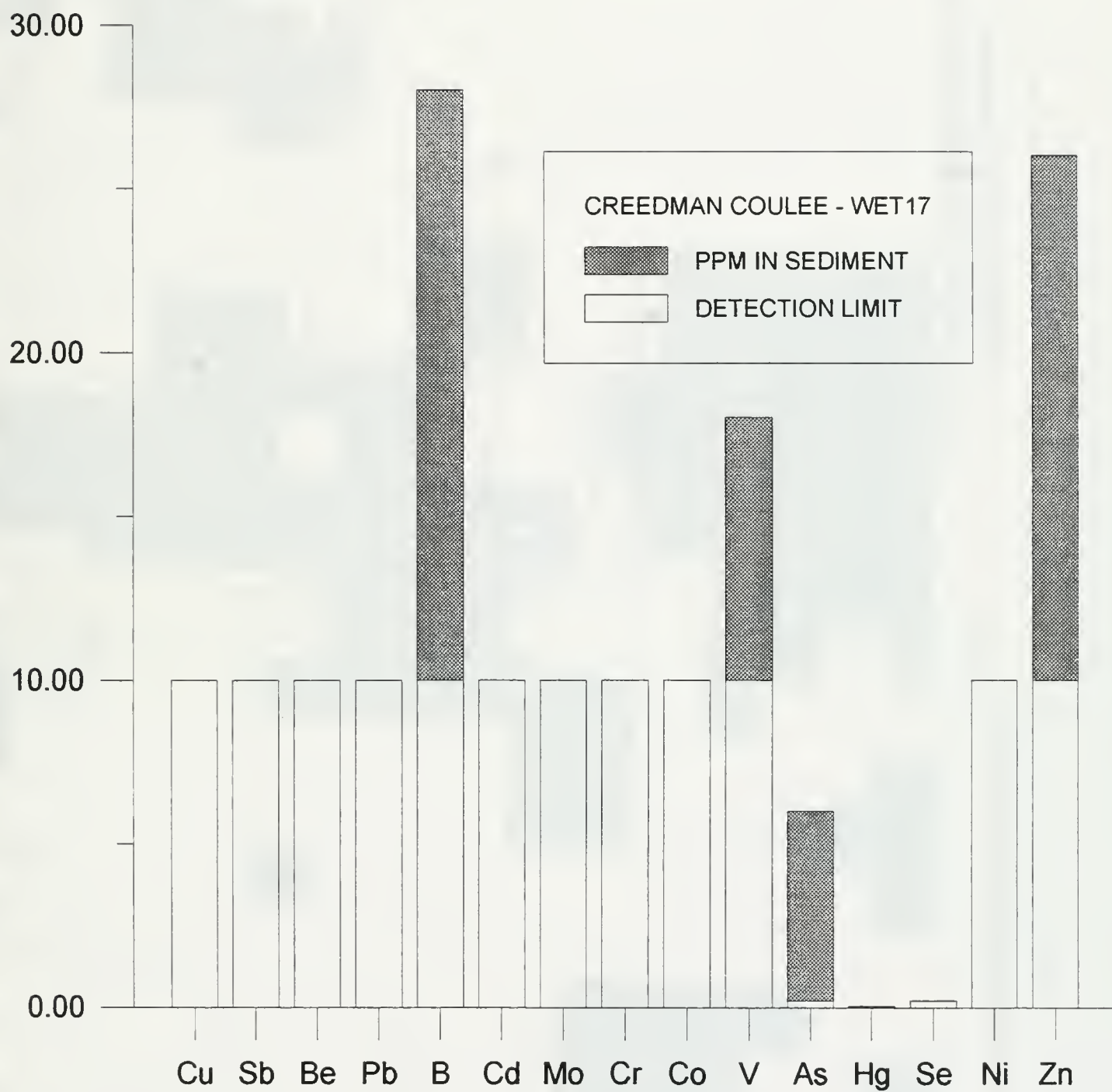


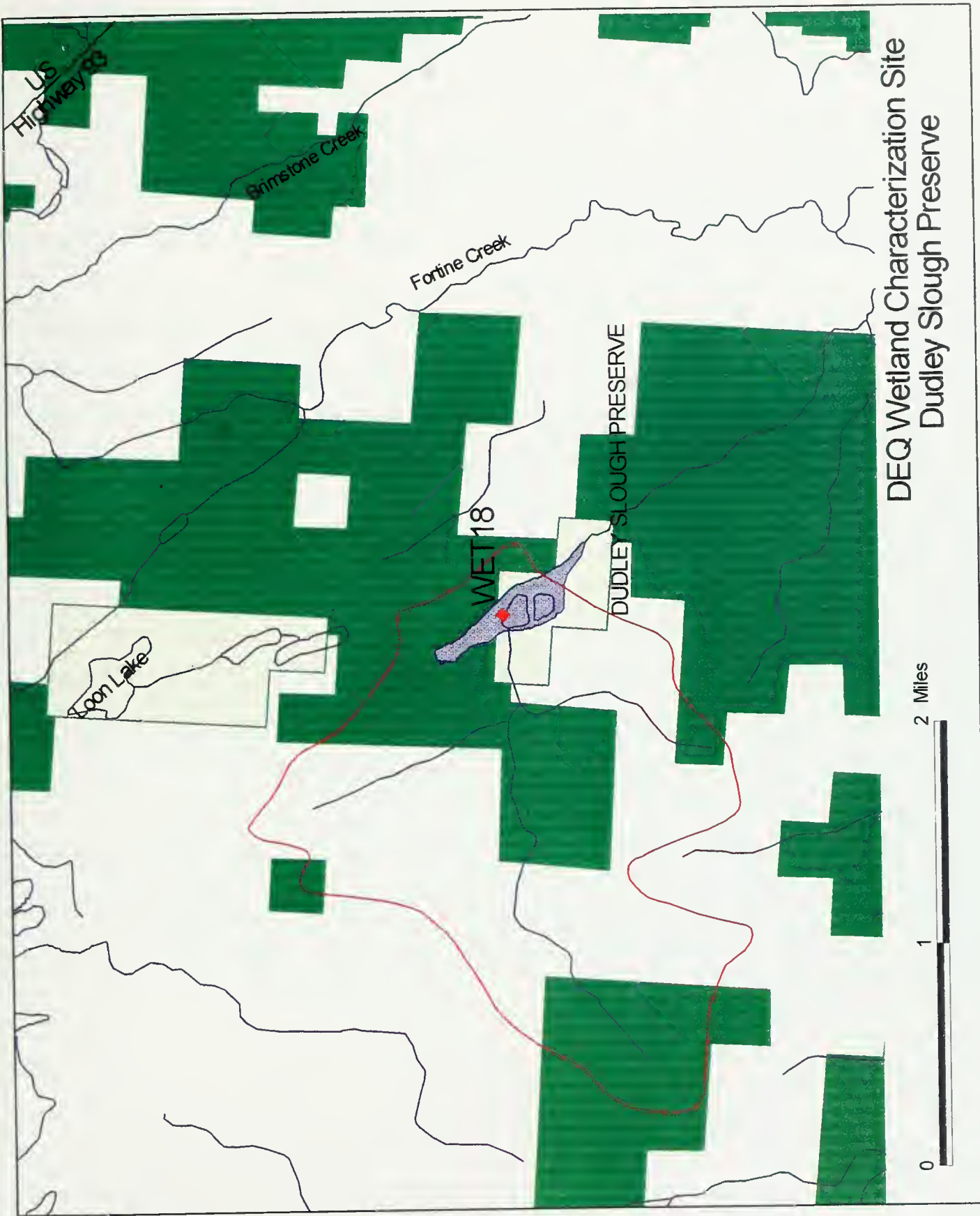
Inches Precipitation



Concentrations in Milligrams per liter







Wetland: DUDLEY SLOUGH PRESERVE

Site Code: WET18

7.5 Minute Quad: EDNA MOUNTAIN

Lat: 48 42 20

Long: 114 55 10

Mean Annual Precipitation in Inches: 19.00

Mean Annual Potential Evaporation (Penman) in Inches: 31.00

'Net Precipitation' in Inches: -12.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 32 acres

Area of contributing drainage basin: 1970 acres

Mapped elevation of wetland surface: 3390 ft

Maximum elevation within drainage basin: 4605 ft

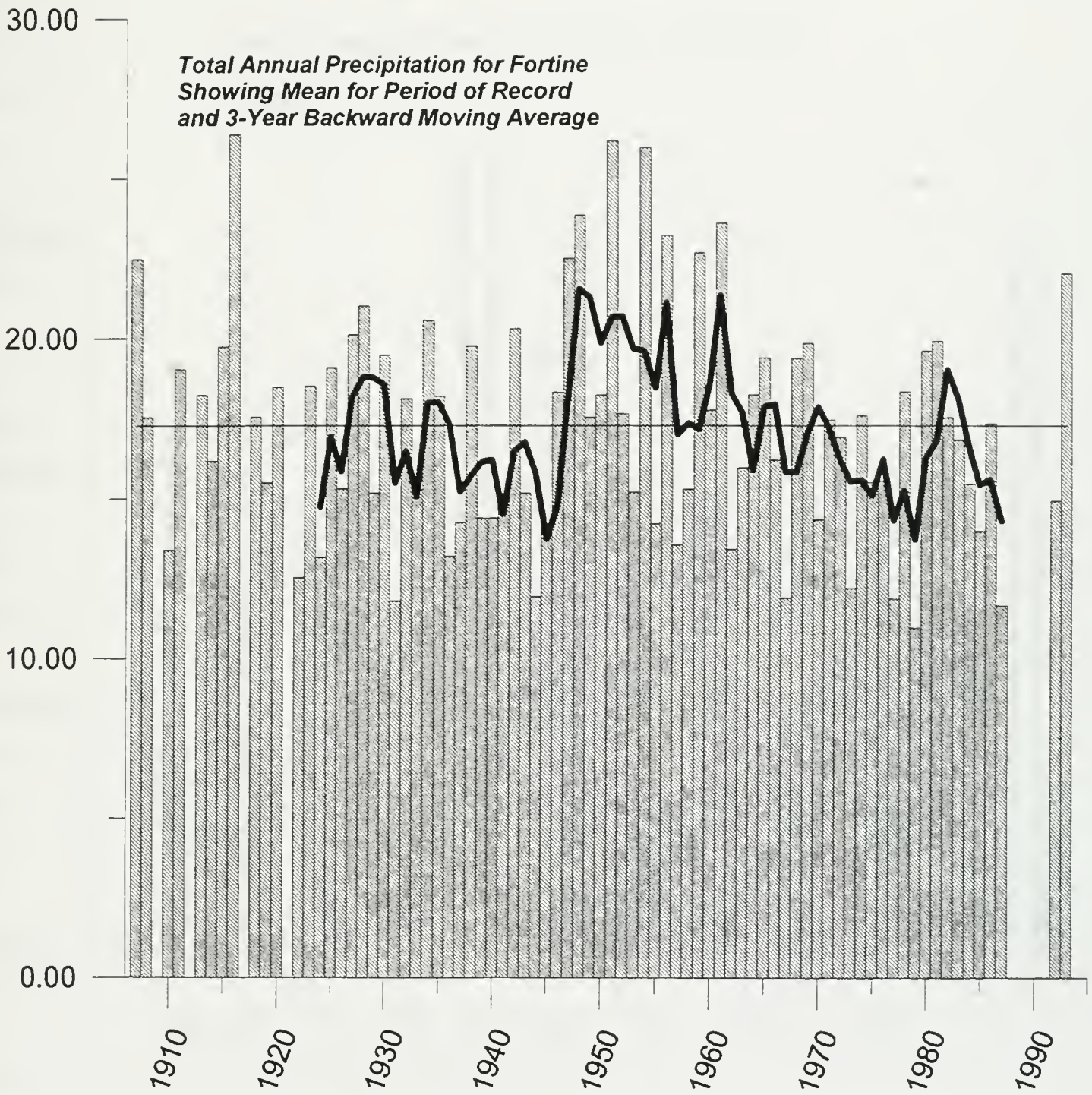
Net relief of contributing basin: 1215 ft

COE Hydrogeomorphic class: DEPRESSIONAL

Primary surficial geologic unit 112DRFT

Primary bedrock geologic unit 400BELT

Annual Precipitation in Inches



Inches Precipitation

8.00

Monthly Average, Maximum and Minimum Precipitation

Fortine

6.00

4.00

2.00

0.00

jan

feb

mar

apr

may

june

july

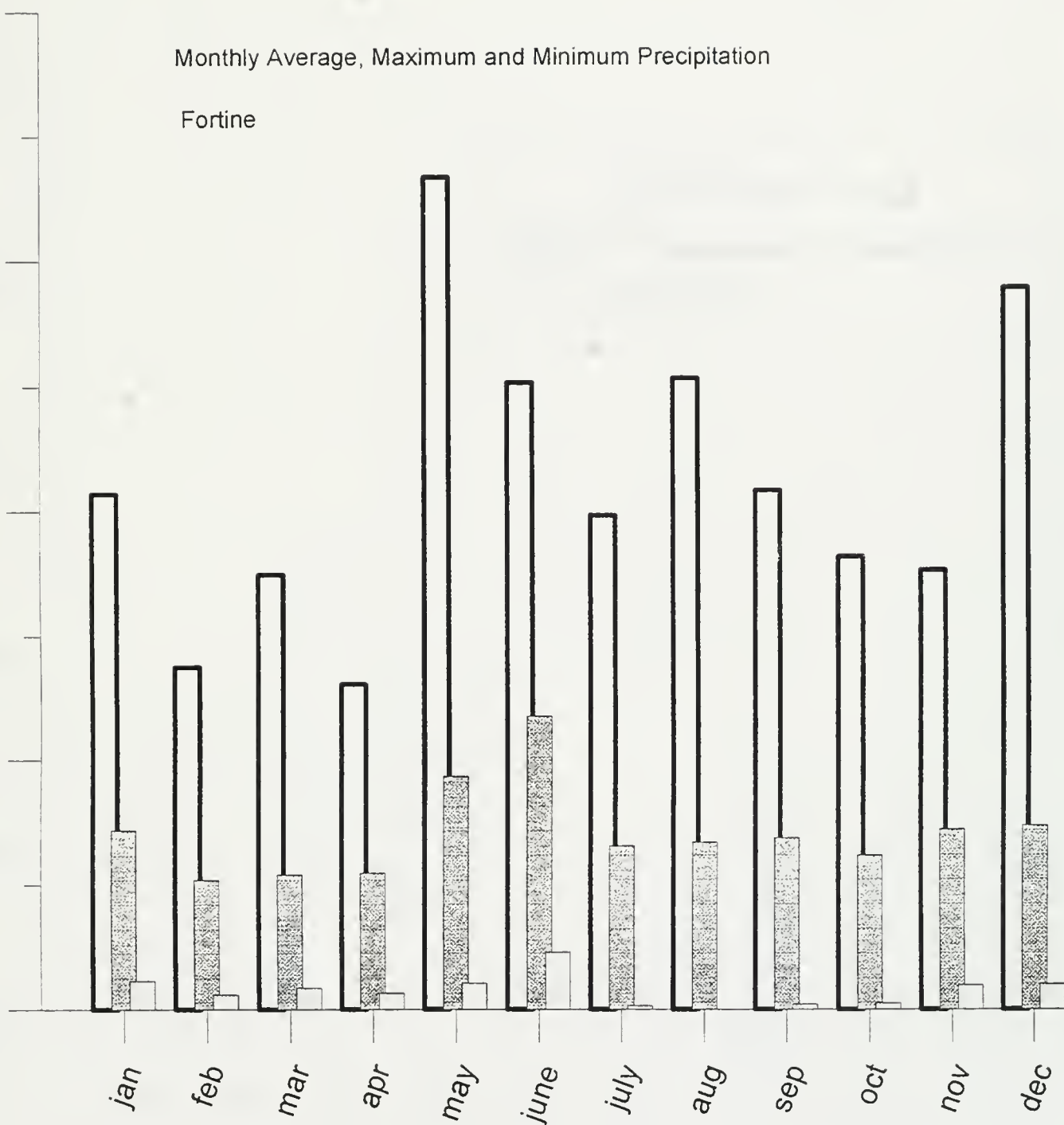
aug

sep

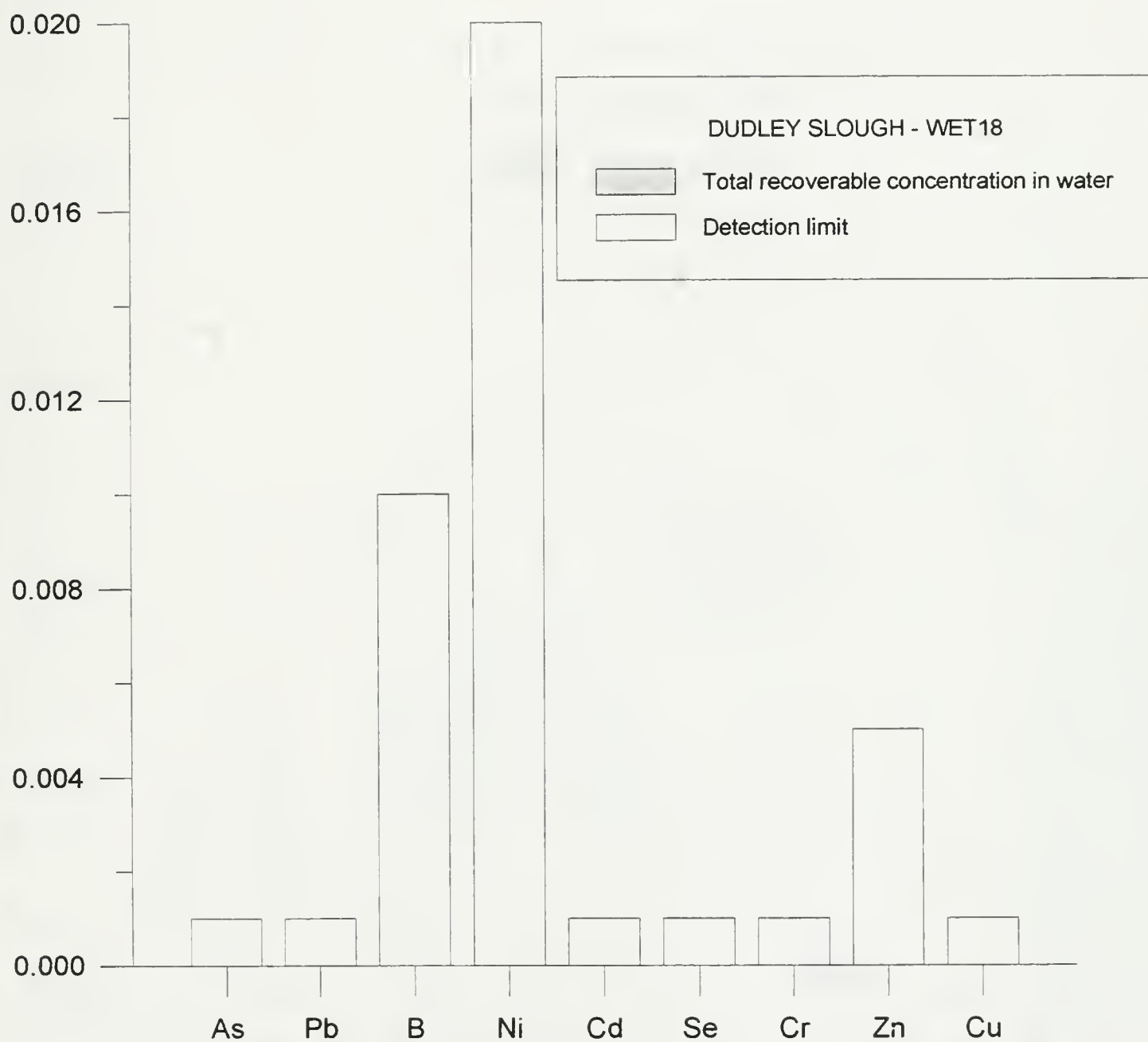
oct

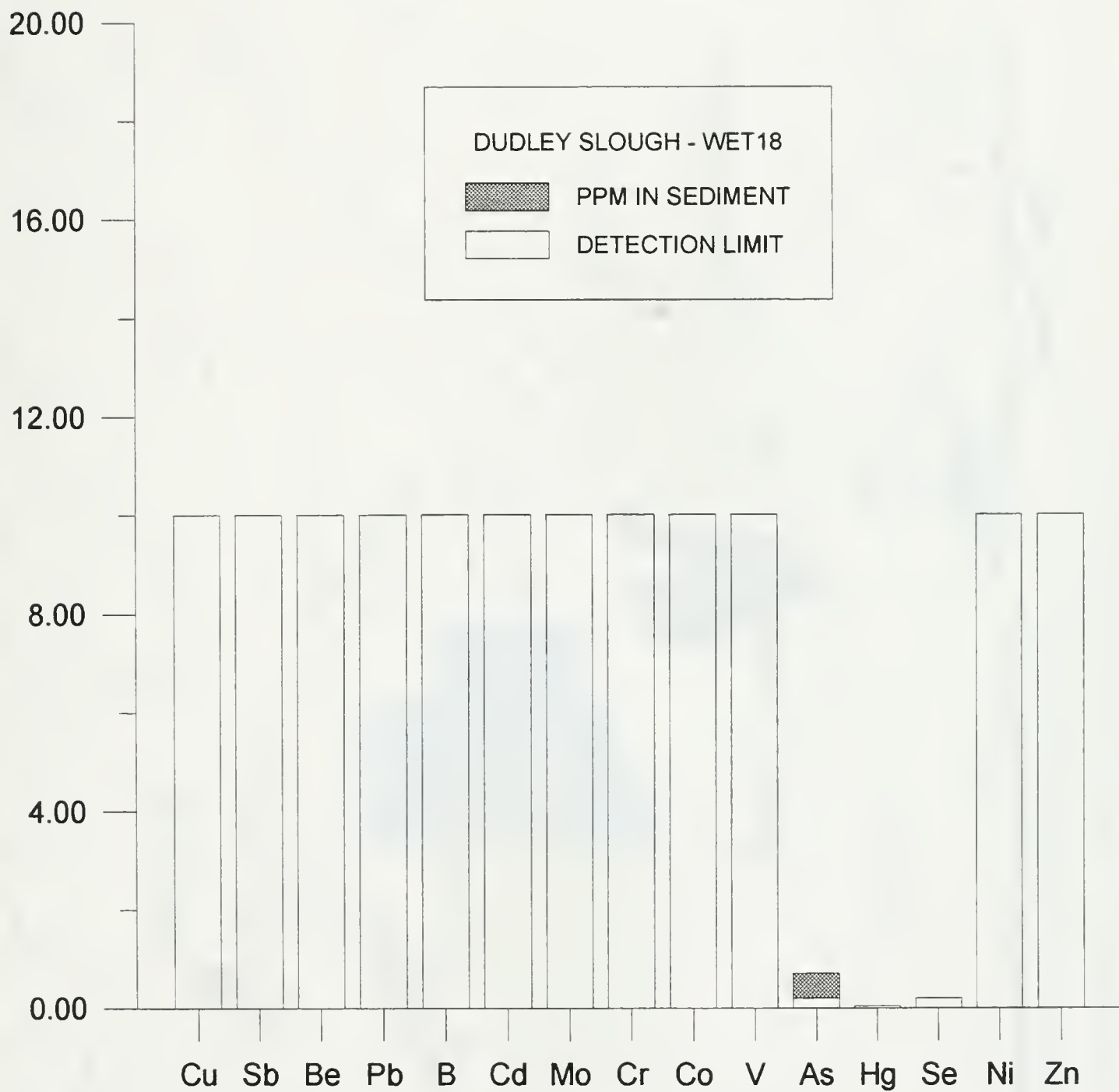
nov

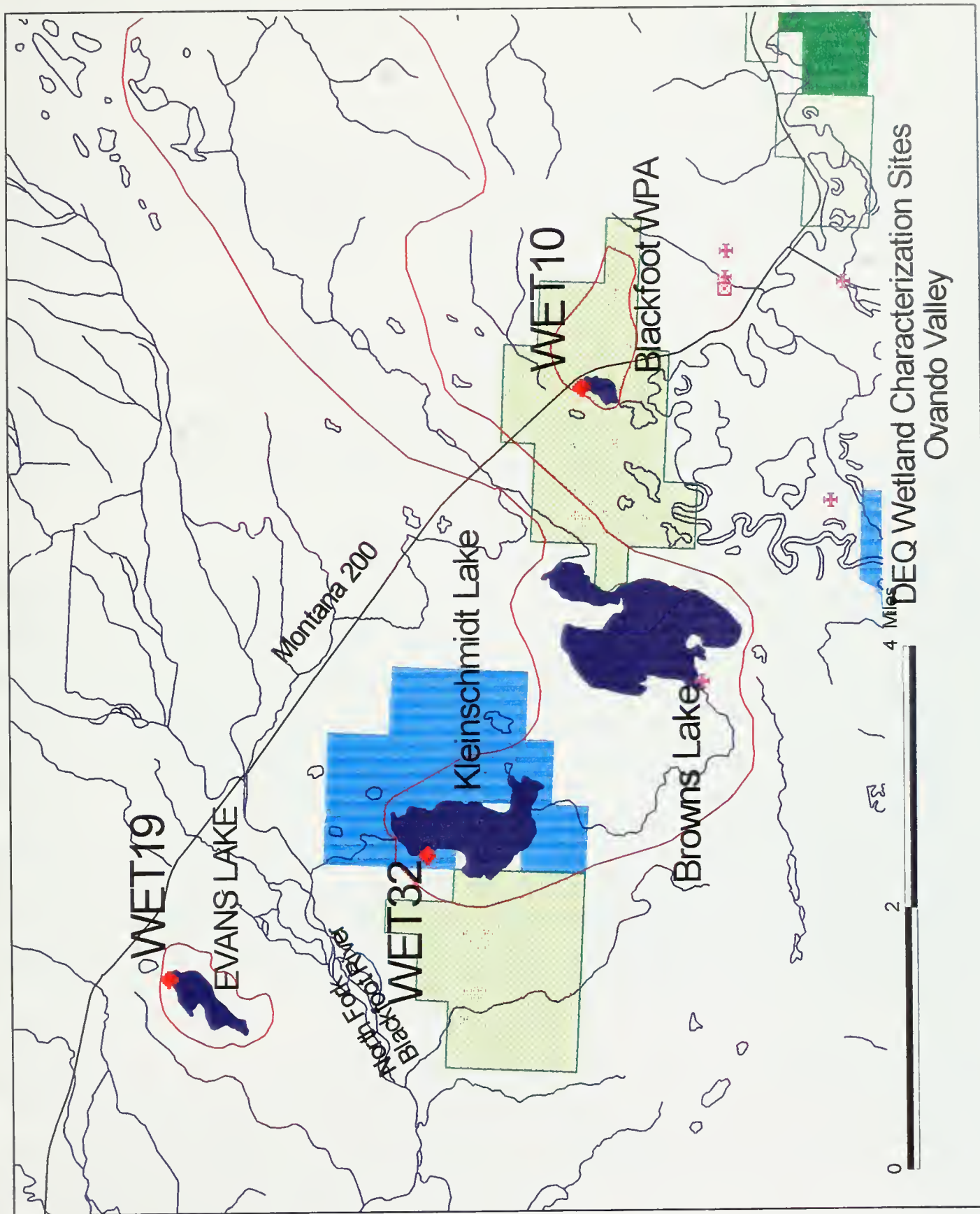
dec



Concentrations in Milligrams per liter







Wetland: EVANS LAKE

Site Code: WET19

7.5 Minute Quad: OVANDO MOUNTAIN

Lat: 47 0 23

Long: 113 4 15

Mean Annual Precipitation in Inches: 17.00

Mean Annual Potential Evaporation (Penman) in Inches: 33.00

'Net Precipitation' in Inches: -16.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 74 acres

Area of contributing drainage basin: 280 acres

Mapped elevation of wetland surface: 4190 ft

Maximum elevation within drainage basin: 4330 ft

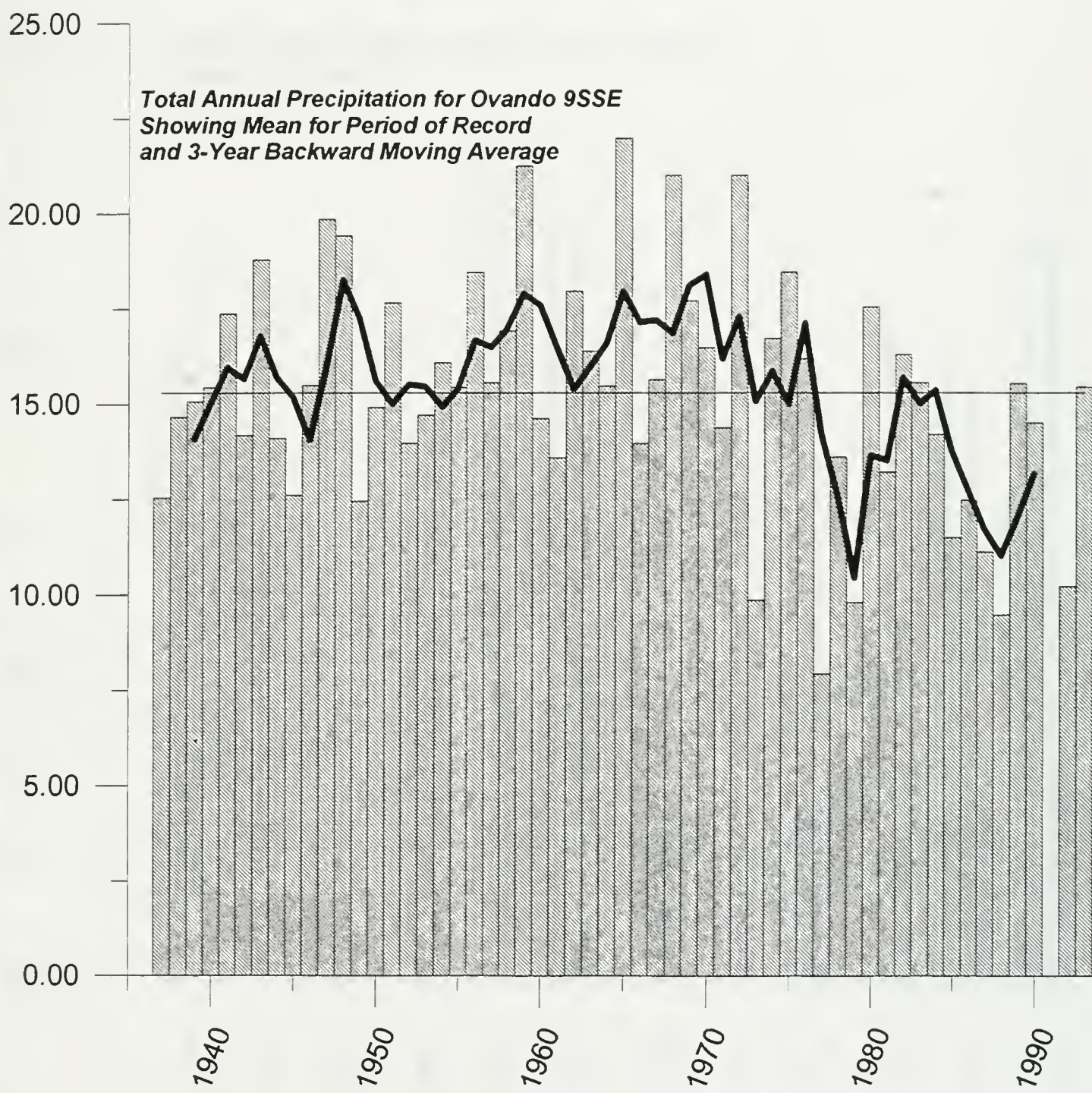
Net relief of contributing basin: 140 ft

COE Hydrogeomorphic class: FRINGE

Primary surficial geologic unit 112TILL

Primary bedrock geologic unit 120SDMS

Annual Precipitation in Inches



Inches Precipitation

6.00

Monthly Average, Maximum and Minimum Precipitation
Ovando 9 SSE Station

4.00

2.00

0.00

jan

feb

mar

apr

may

june

july

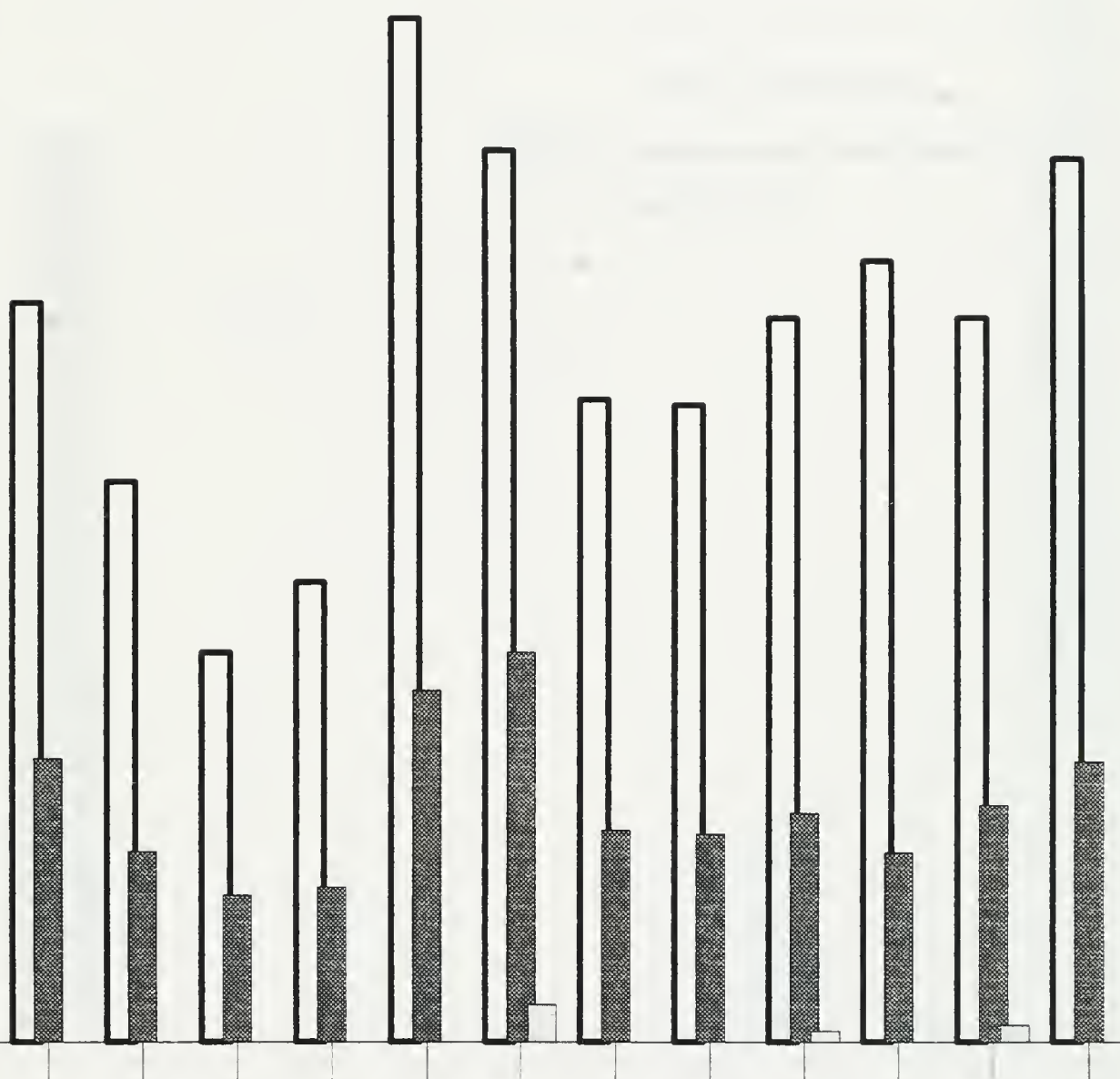
aug

sep

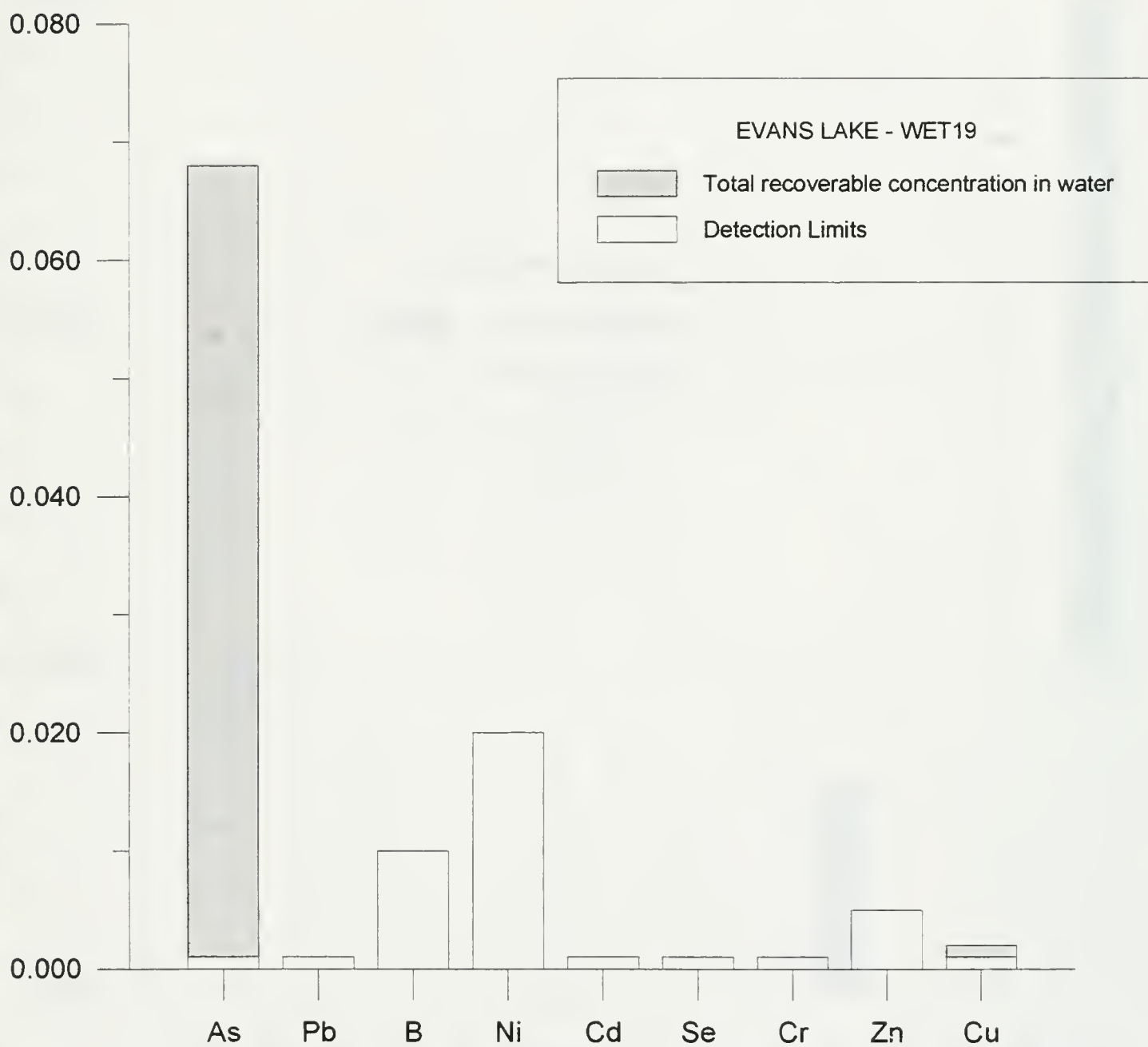
oct

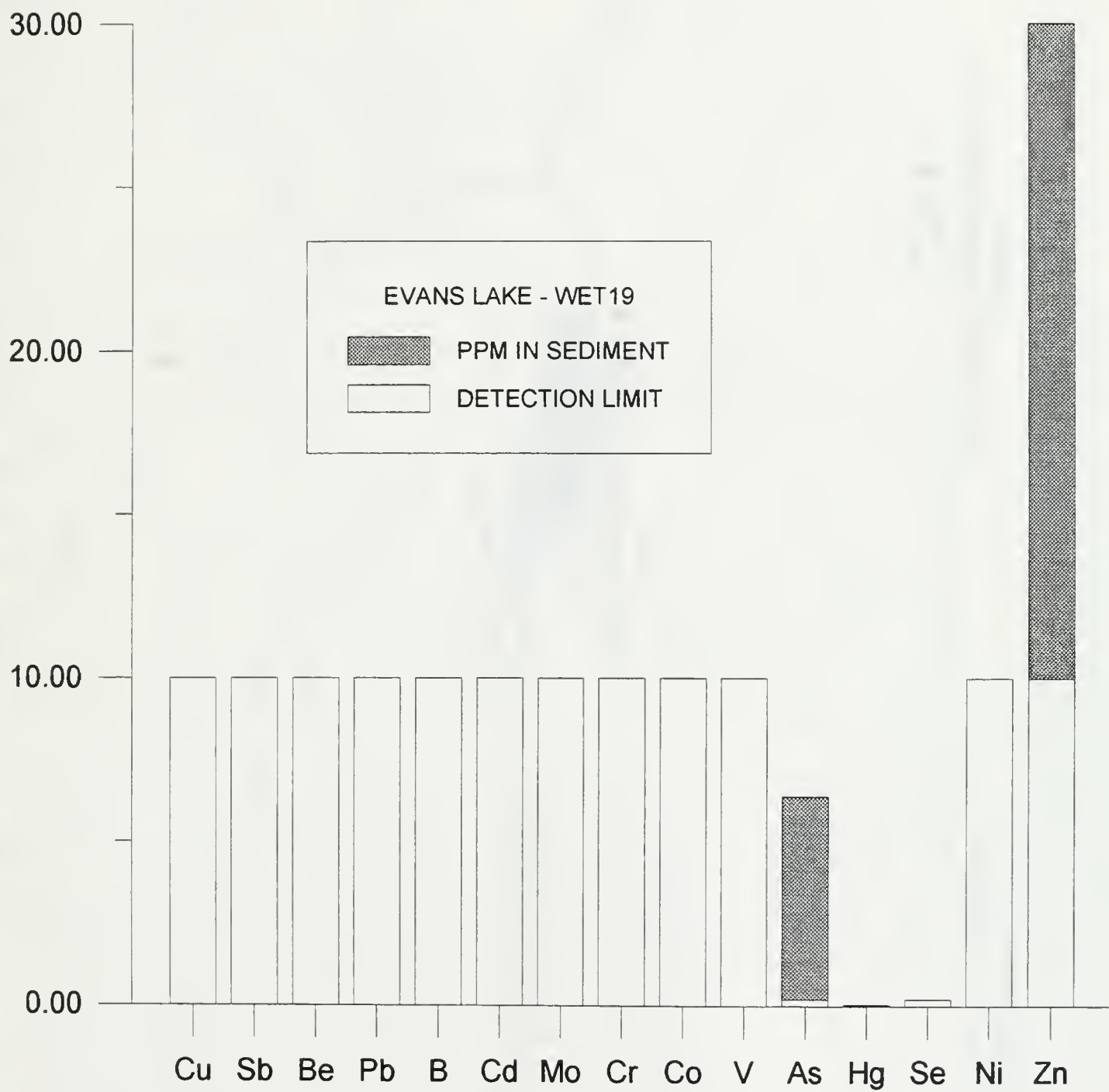
nov

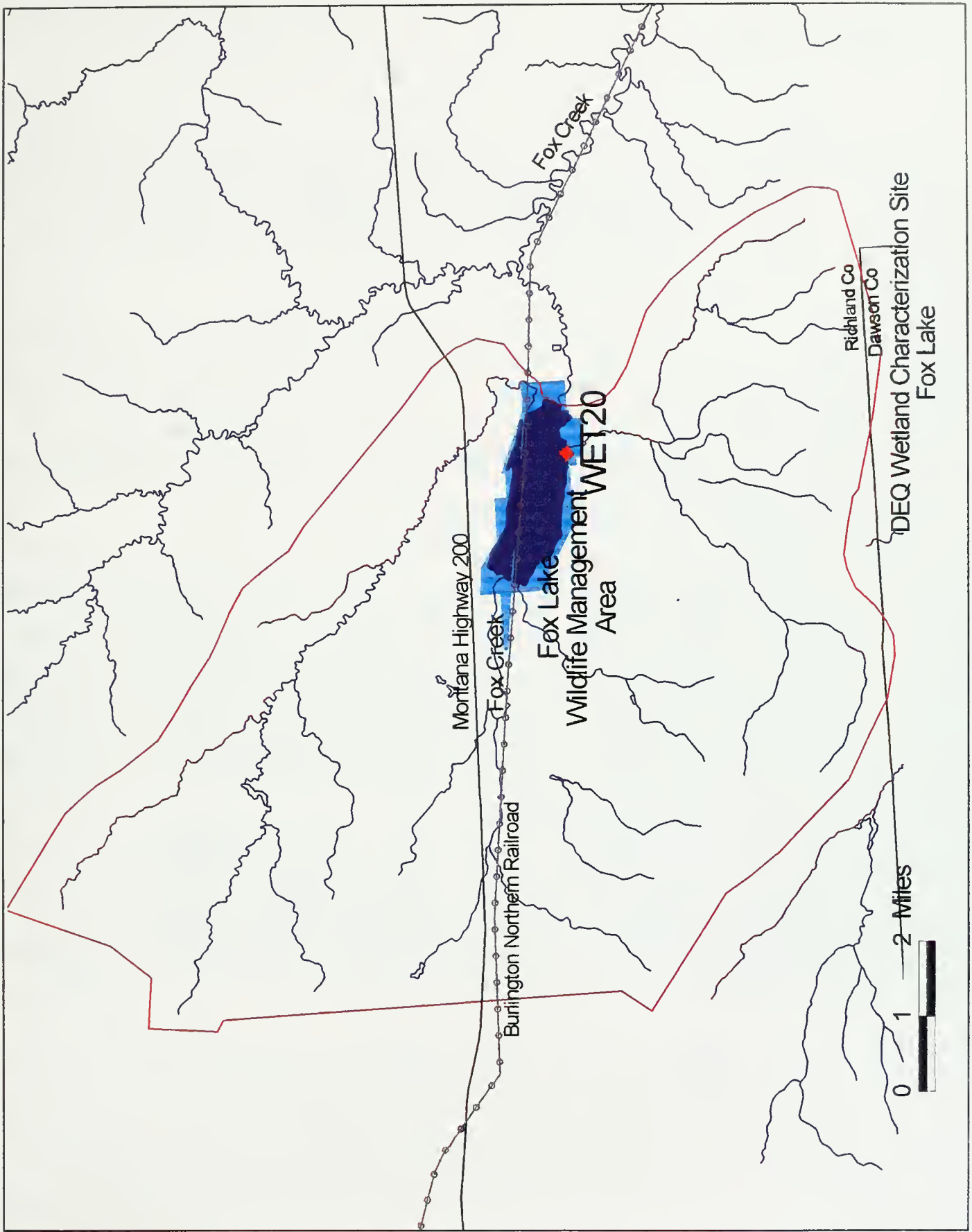
dec



Concentrations in Milligrams per liter







Wetland: FOX LAKE

Site Code: WET20

7.5 Minute Quad: FOX LAKE

Lat: 47 40 25

Long: 104 38 45

Mean Annual Precipitation in Inches: 13.00

Mean Annual Potential Evaporation (Penman) in Inches: 38.00

'Net Precipitation' in Inches: -25.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 920 acres

Area of contributing drainage basin: 48058 acres

Mapped elevation of wetland surface: 2342 ft

Maximum elevation within drainage basin: 2805 ft

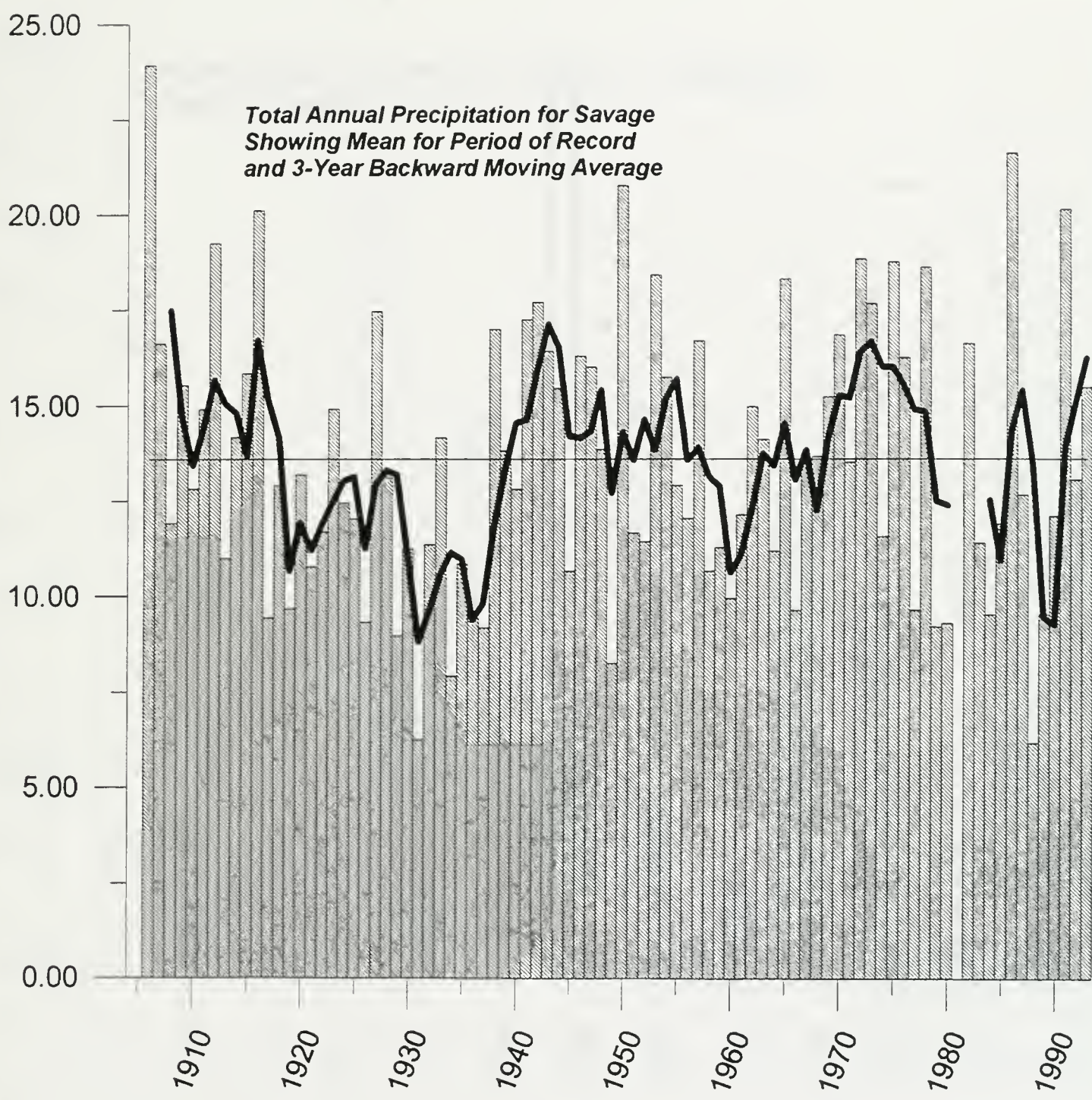
Net relief of contributing basin: 463 ft

COE Hydrogeomorphic class: FRINGE

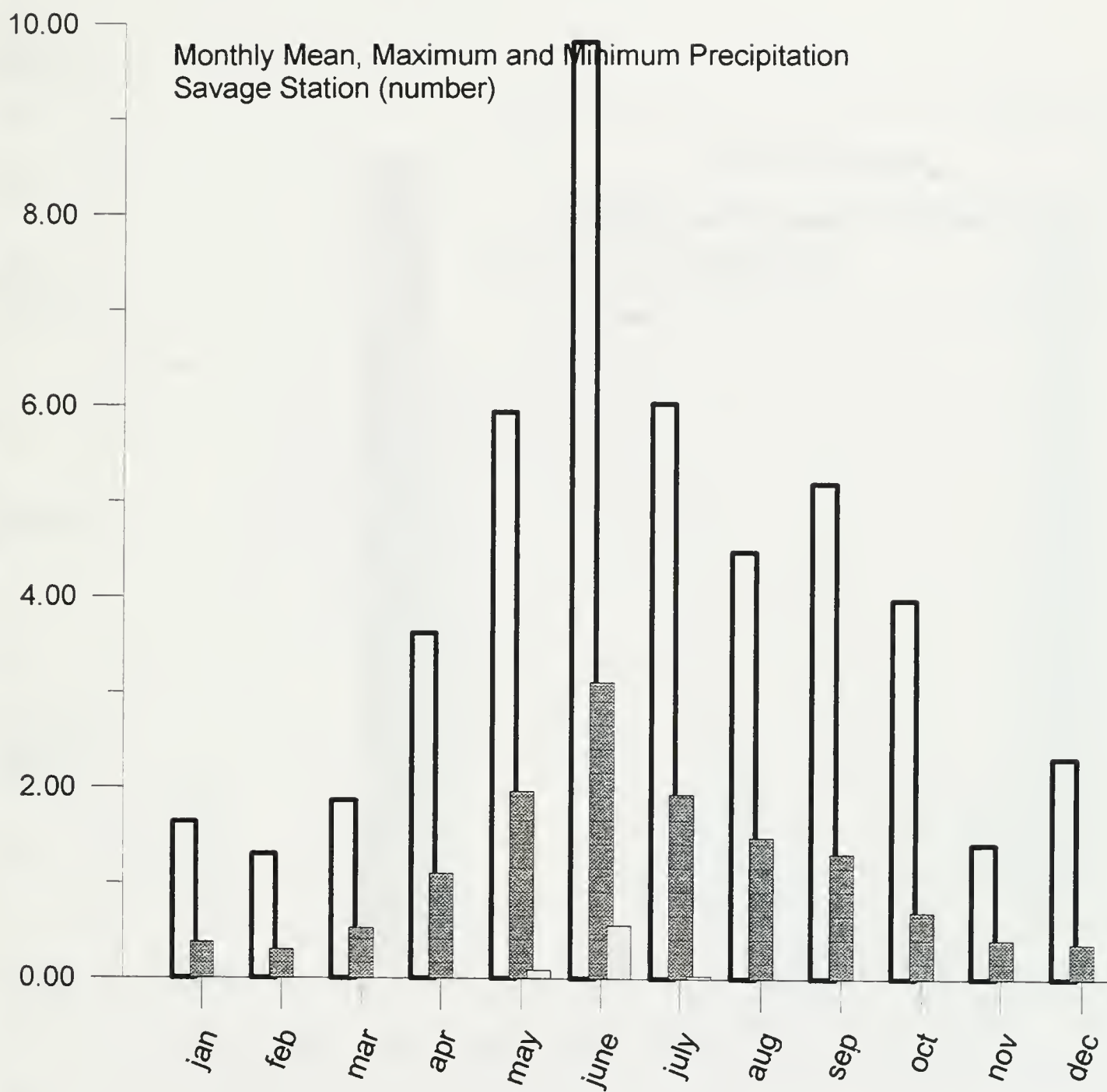
Primary surficial geologic unit 110"LAC"

Primary bedrock geologic unit 125TLCK

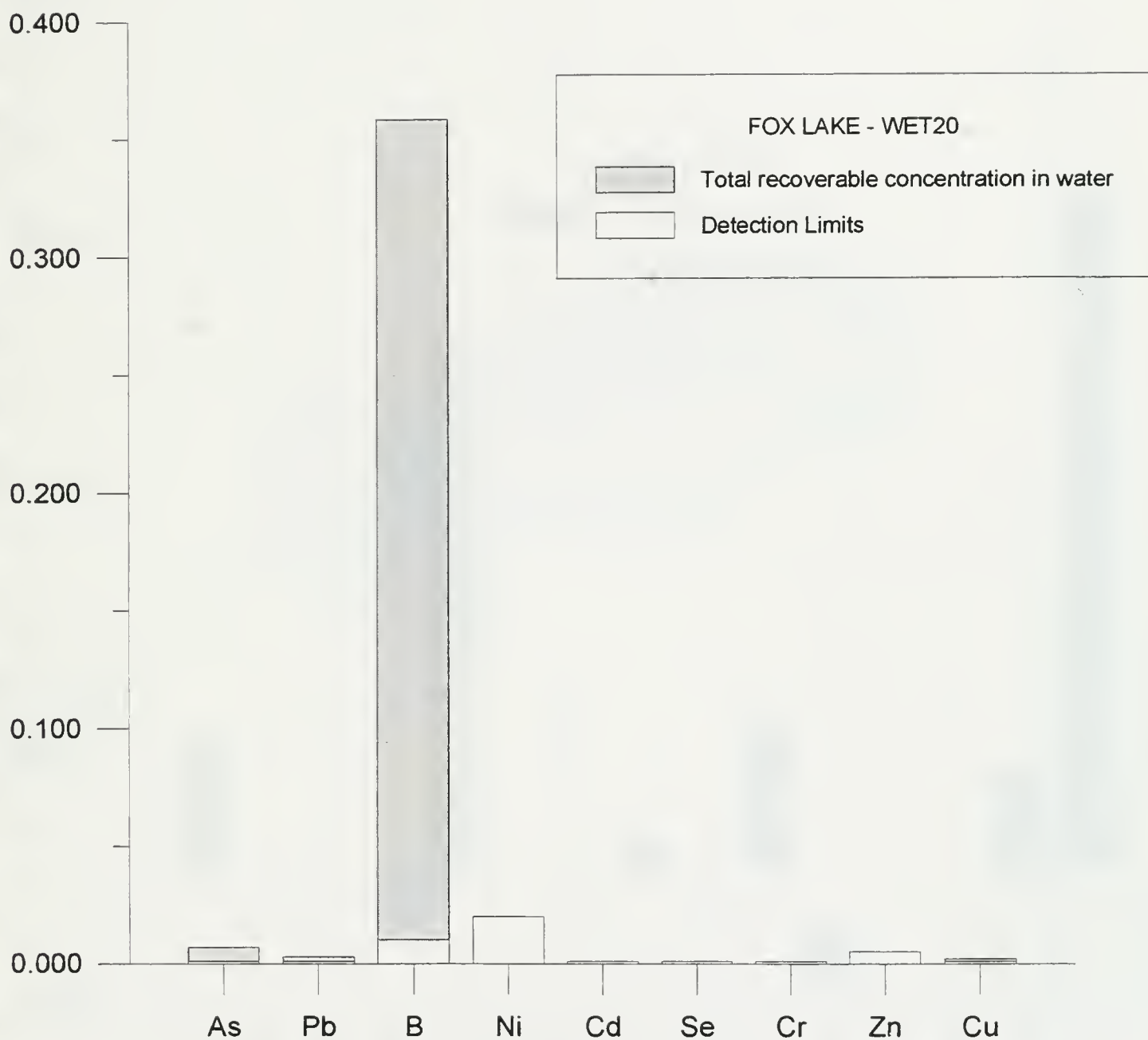
Annual Precipitation in Inches

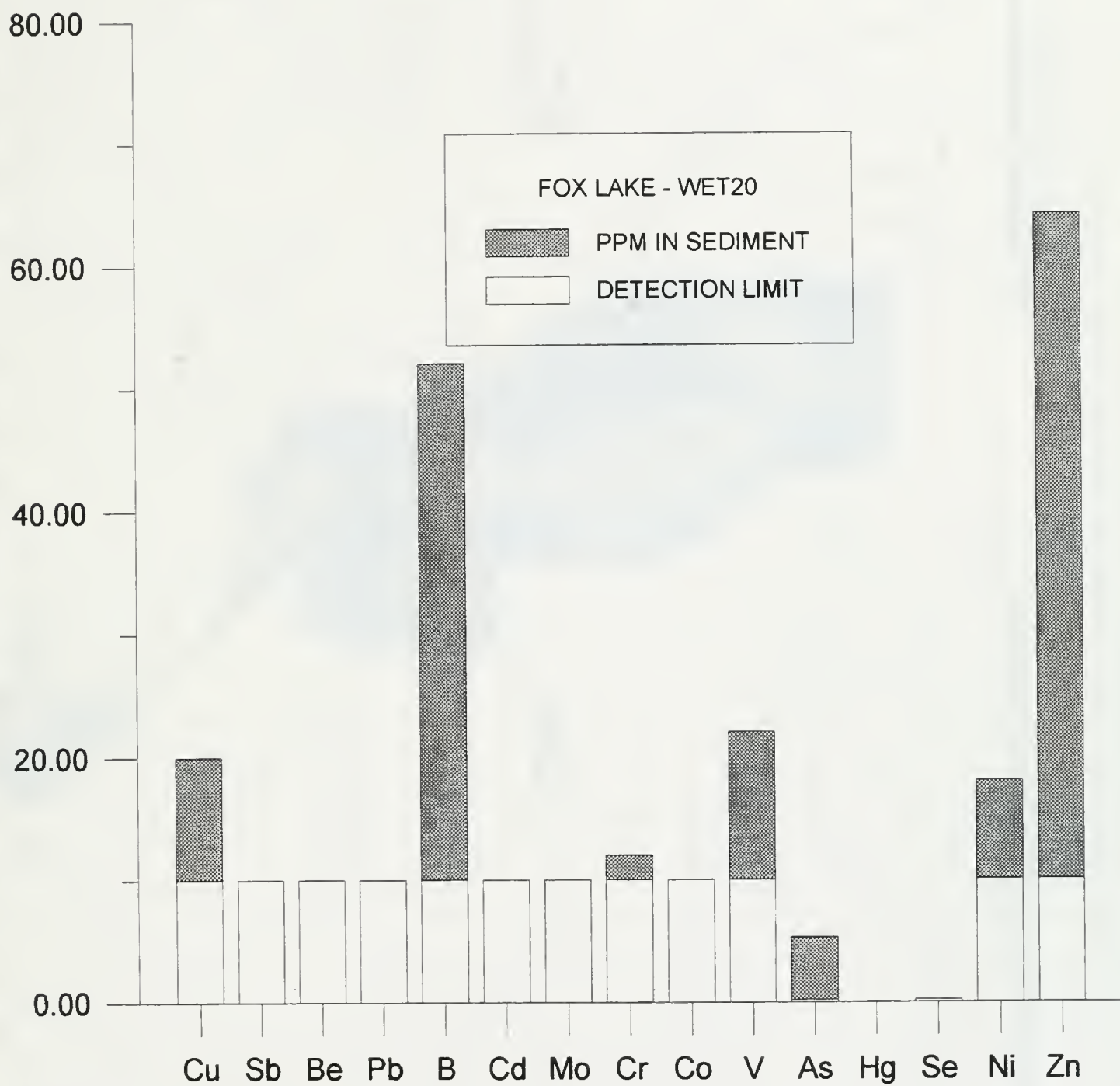


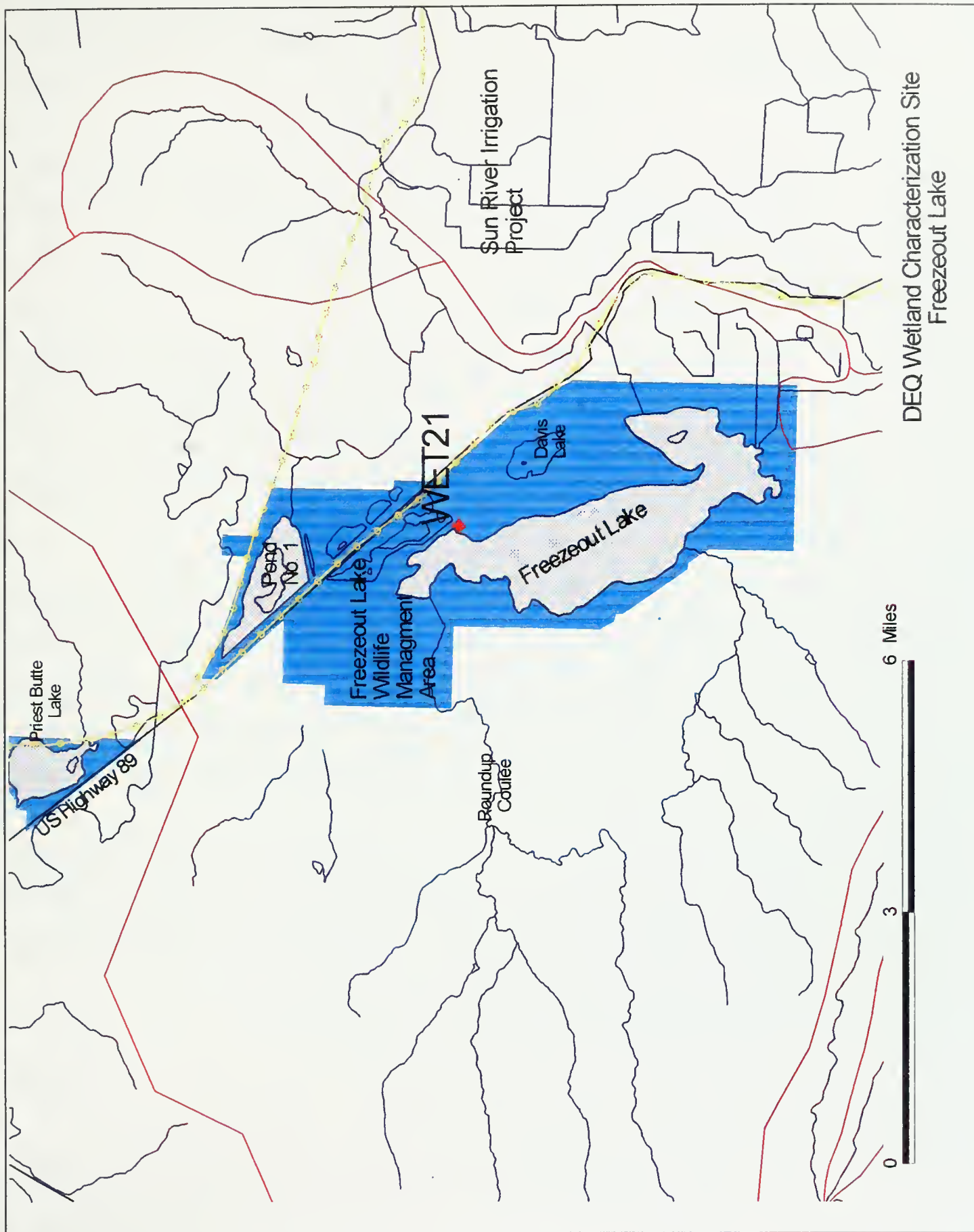
Inches Precipitation



Concentrations in Milligrams per liter







DEQ Wetland Characterization Site
Freezeout Lake

Wetland: FREEZOUT LAKE

Site Code: WET21

7.5 Minute Quad: FREEZEOUT LAKE

Lat: 47 41 0

Long: 112 2 50

Mean Annual Precipitation in Inches: 13.00

Mean Annual Potential Evaporation (Penman) in Inches: 40.00

'Net Precipitation' in Inches: -27.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is artificially impounded.

Site has significant water imports.

Mapped area of wetland: 2589 acres

Area of contributing drainage basin: 67400 acres

Mapped elevation of wetland surface: 3765 ft

Maximum elevation within drainage basin: 4650 ft

Net relief of contributing basin: 885 ft

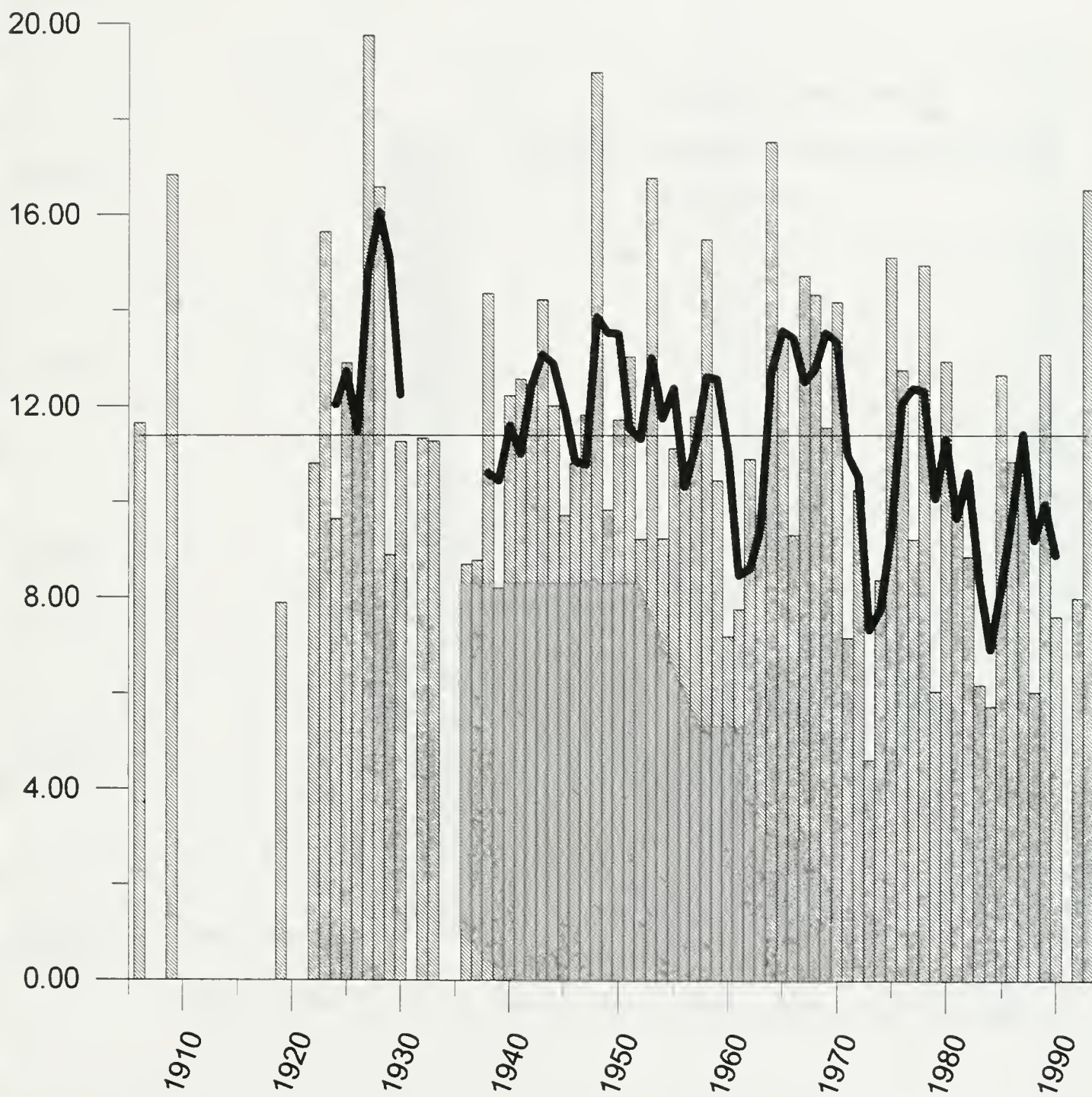
COE Hydrogeomorphic class: FRINGE

Primary surficial geologic unit 112GLCC

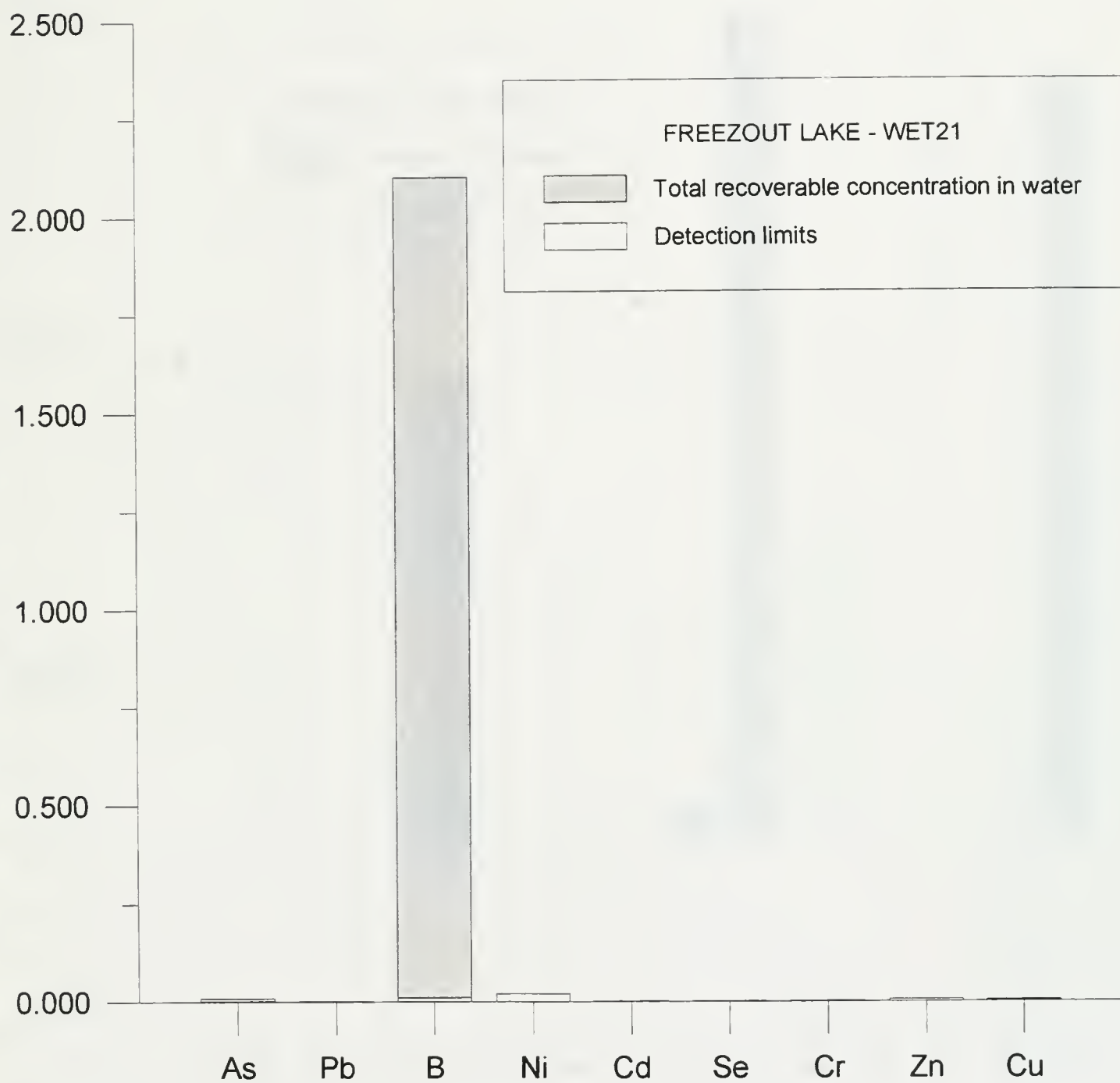
Primary bedrock geologic unit 210CRCS

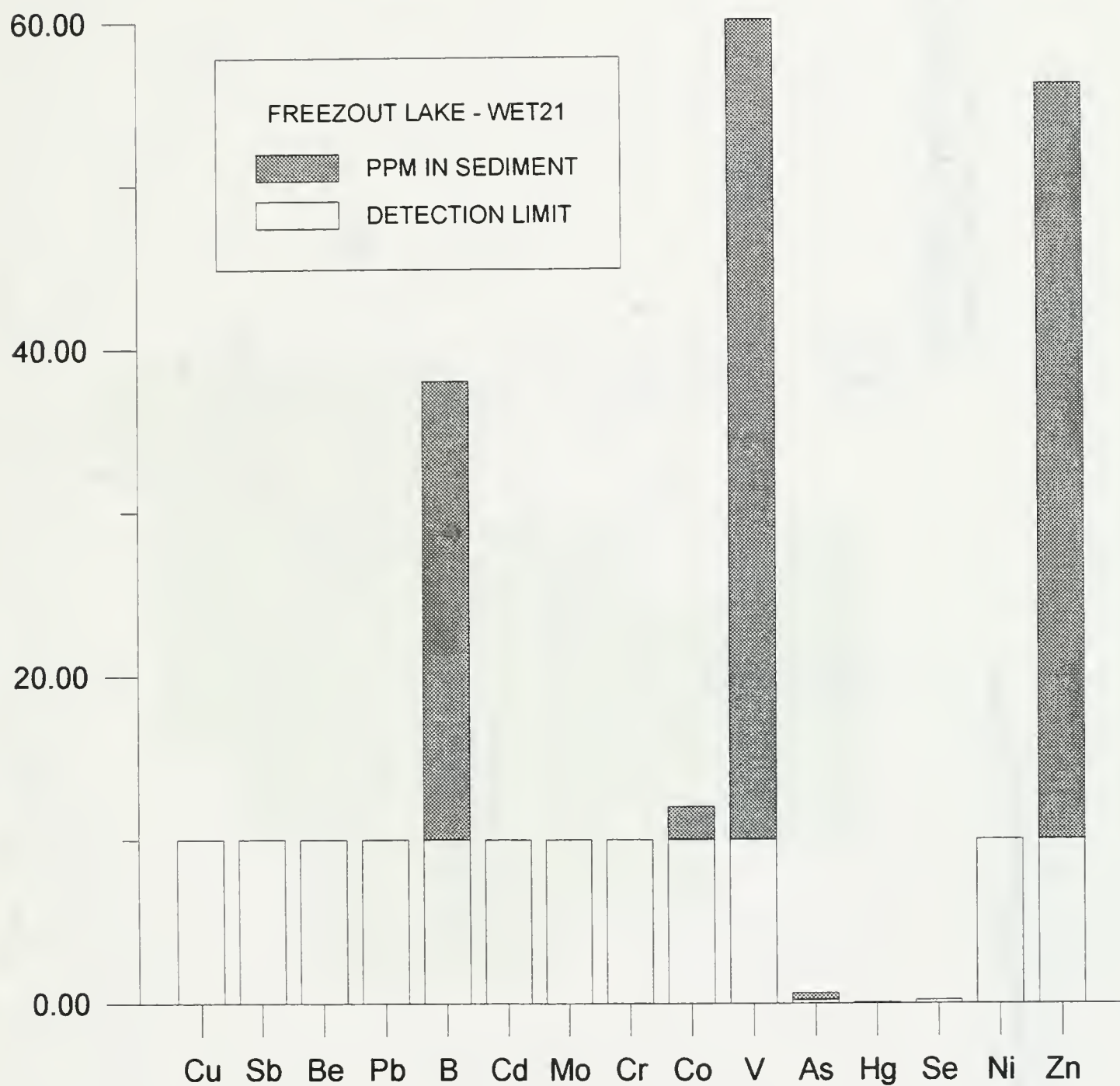
Total Annual Precipitation for Choteau
Showing Mean for Period of Record
and 3-Year Backward Moving Average

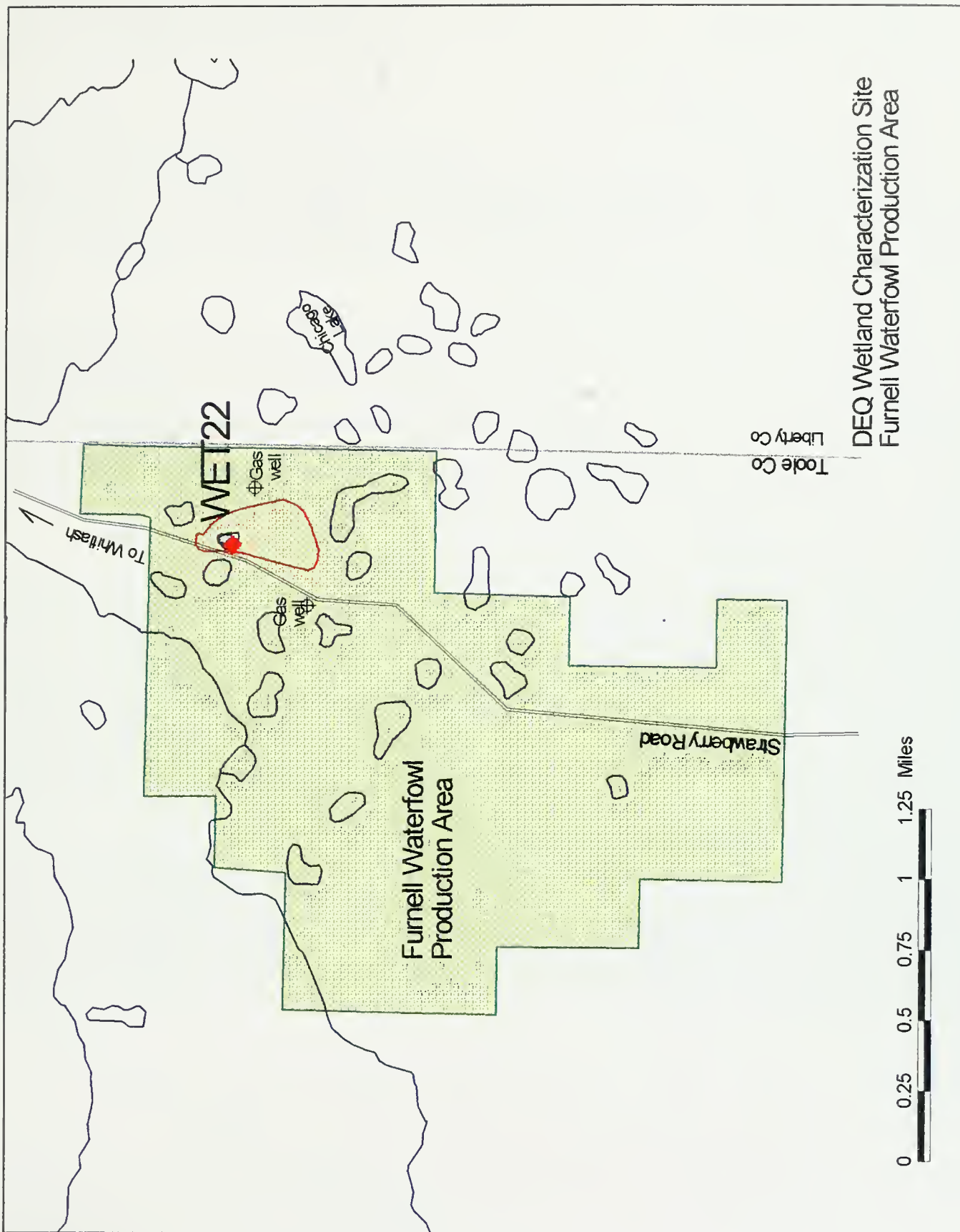
Annual Precipitation in Inches



Concentrations in Milligrams per liter

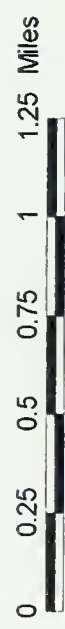






Toole Co
Liberty Co

DEQ Wetland Characterization Site
Furnell Waterfowl Production Area



Wetland: FURNELL WPA

Site Code: WET22

7.5 Minute Quad: GRASSY BUTTE

Lat: 48 52 12

Long: 111 16 50

Mean Annual Precipitation in Inches: 17.00

Mean Annual Potential Evaporation (Penman) in Inches: 36.00

'Net Precipitation' in Inches: -19.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 2 acres

Area of contributing drainage basin: 44 acres

Mapped elevation of wetland surface: 4135 ft

Maximum elevation within drainage basin: 4221 ft

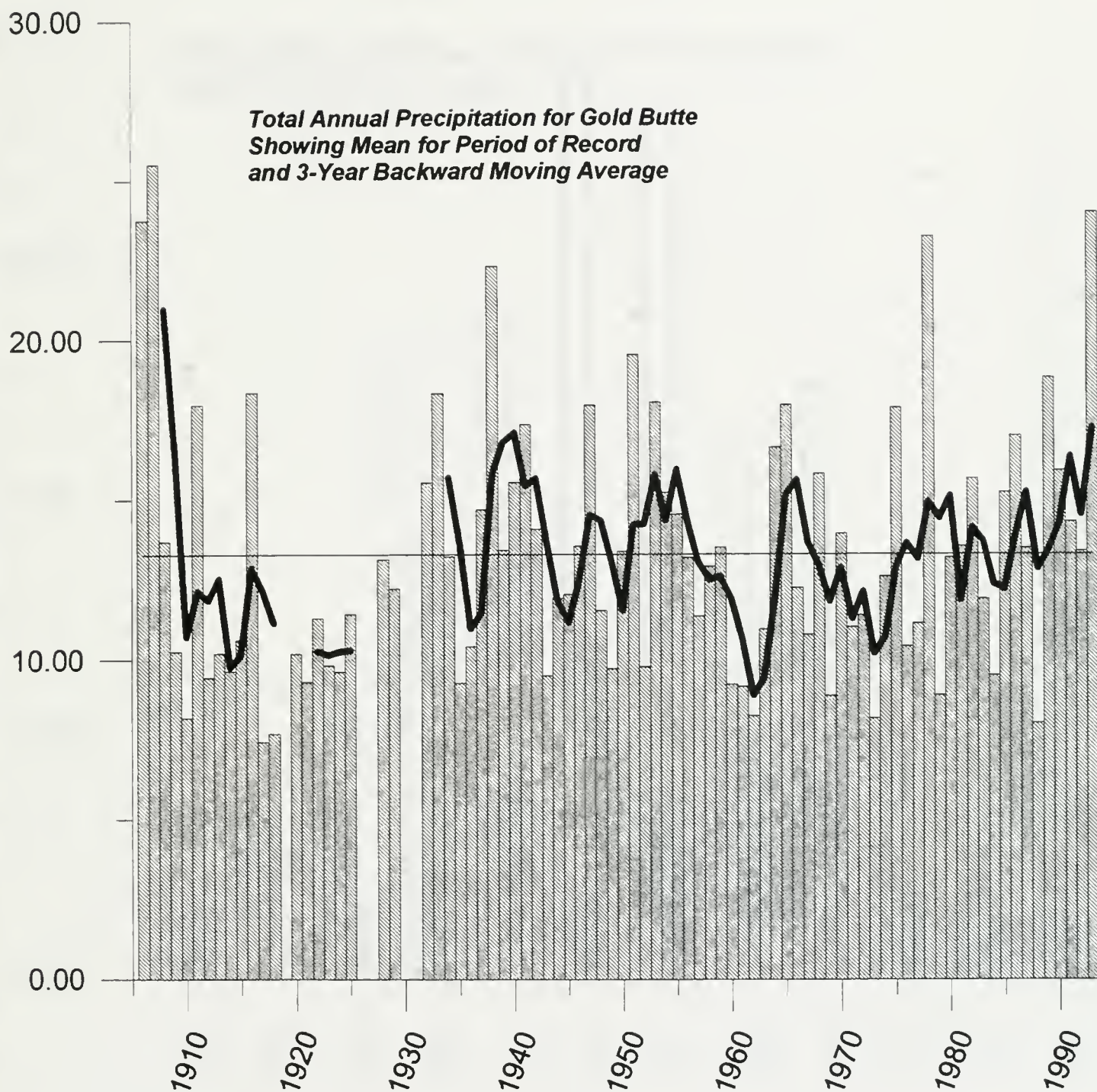
Net relief of contributing basin: 86 ft

COE Hydrogeomorphic class: DEPRESSIONAL

Primary surficial geologic unit 112TILL

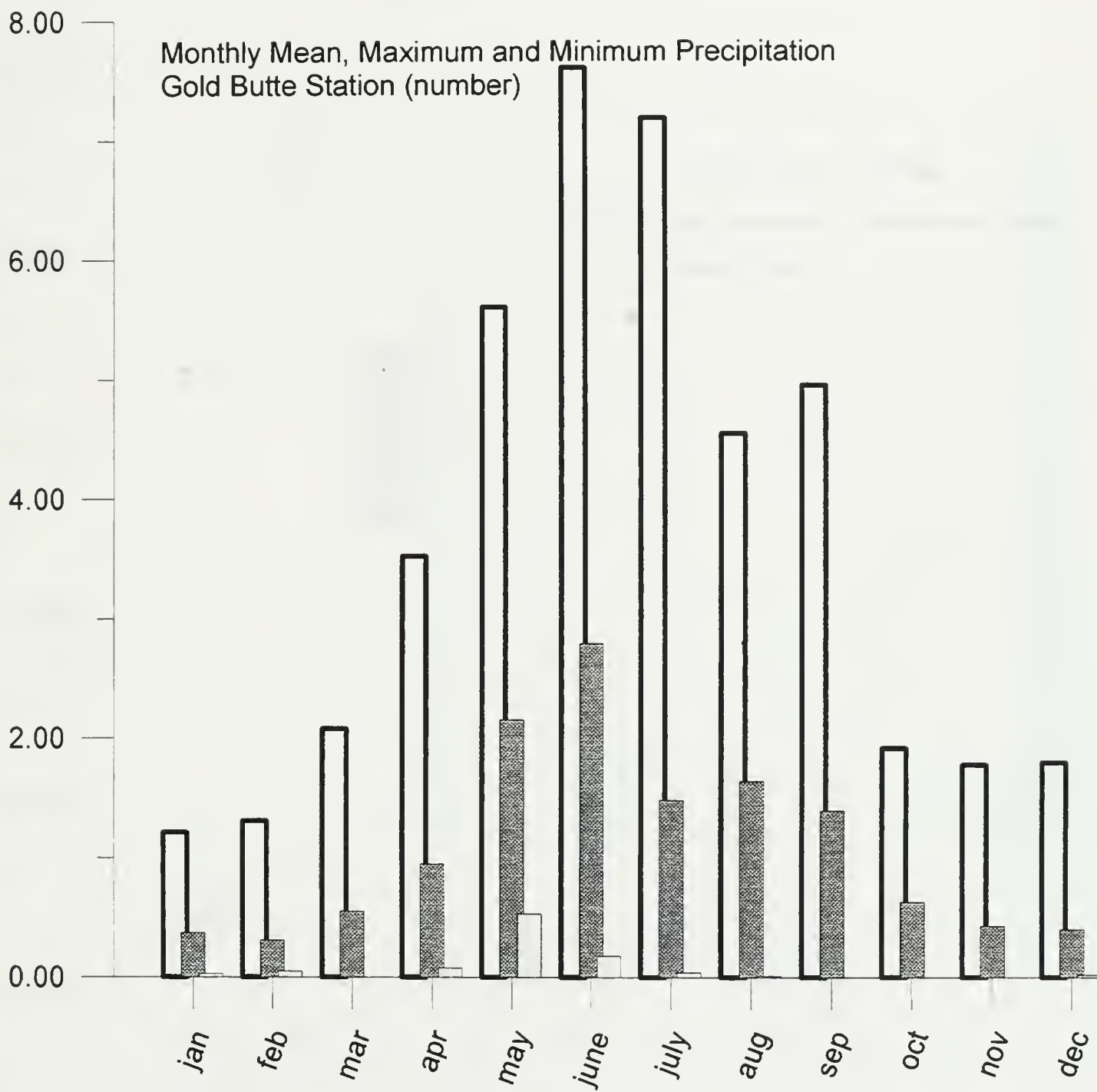
Primary bedrock geologic unit 211CLGG

Annual Precipitation in Inches

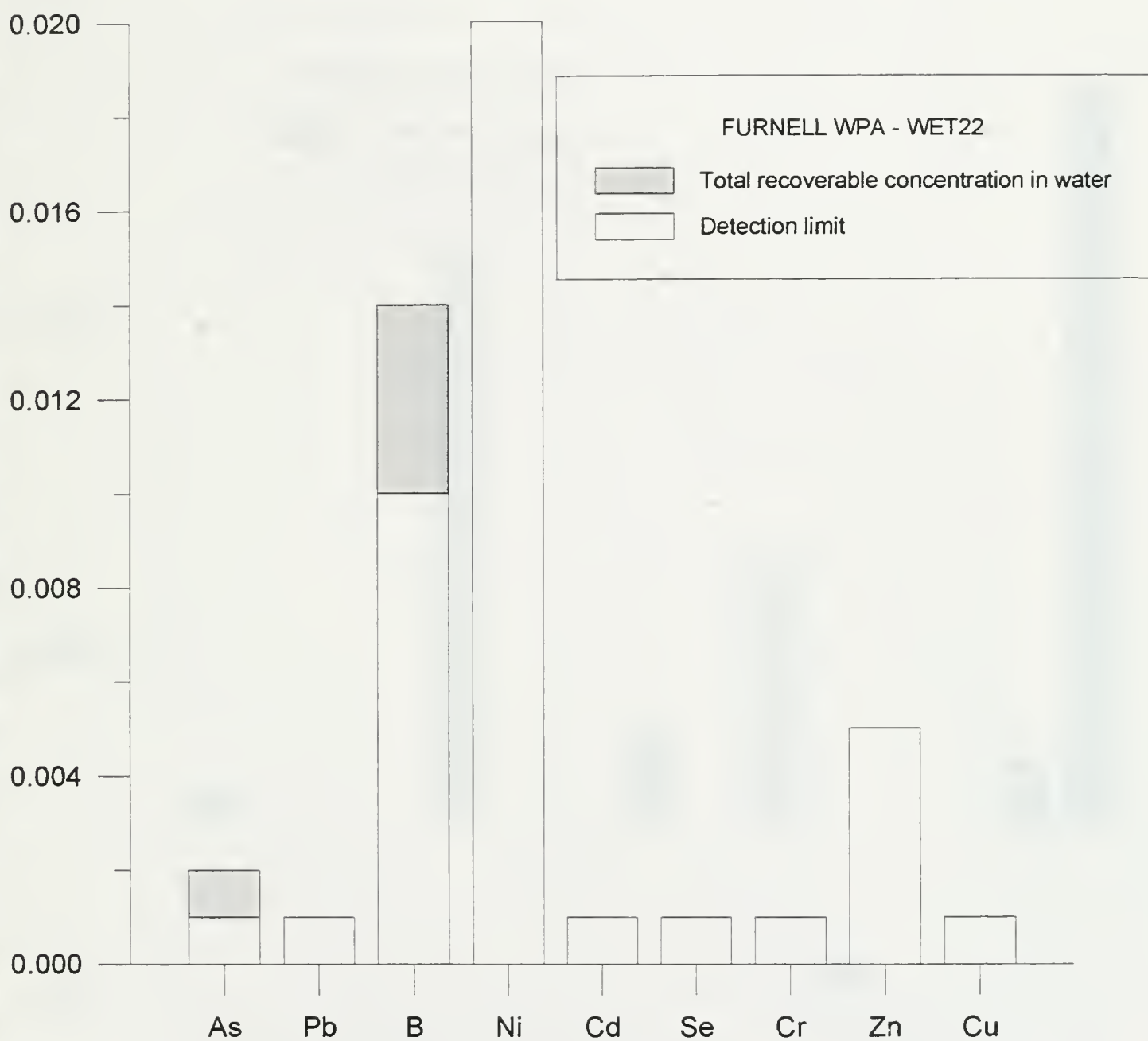


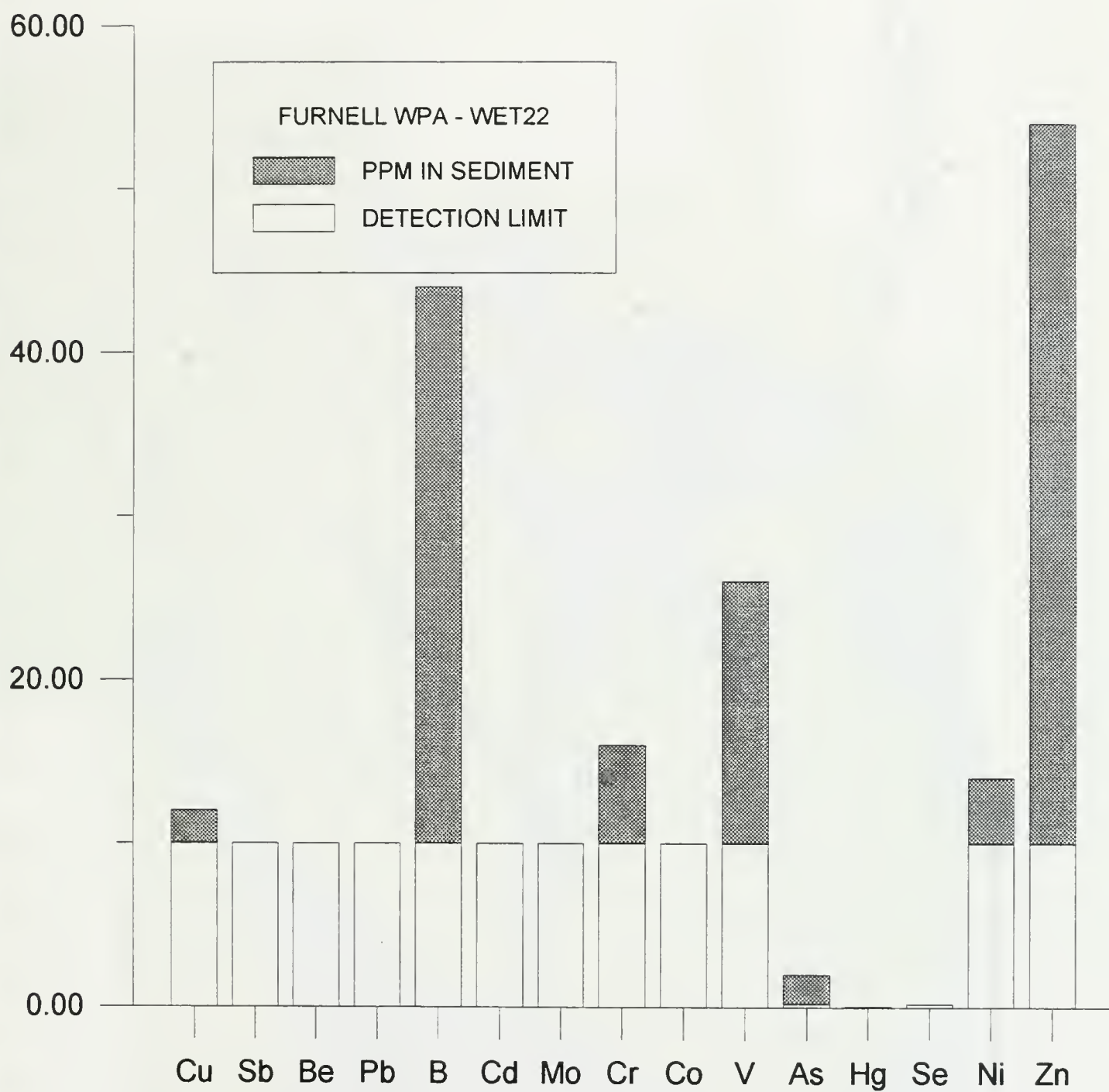
Monthly Mean, Maximum and Minimum Precipitation
Gold Butte Station (number)

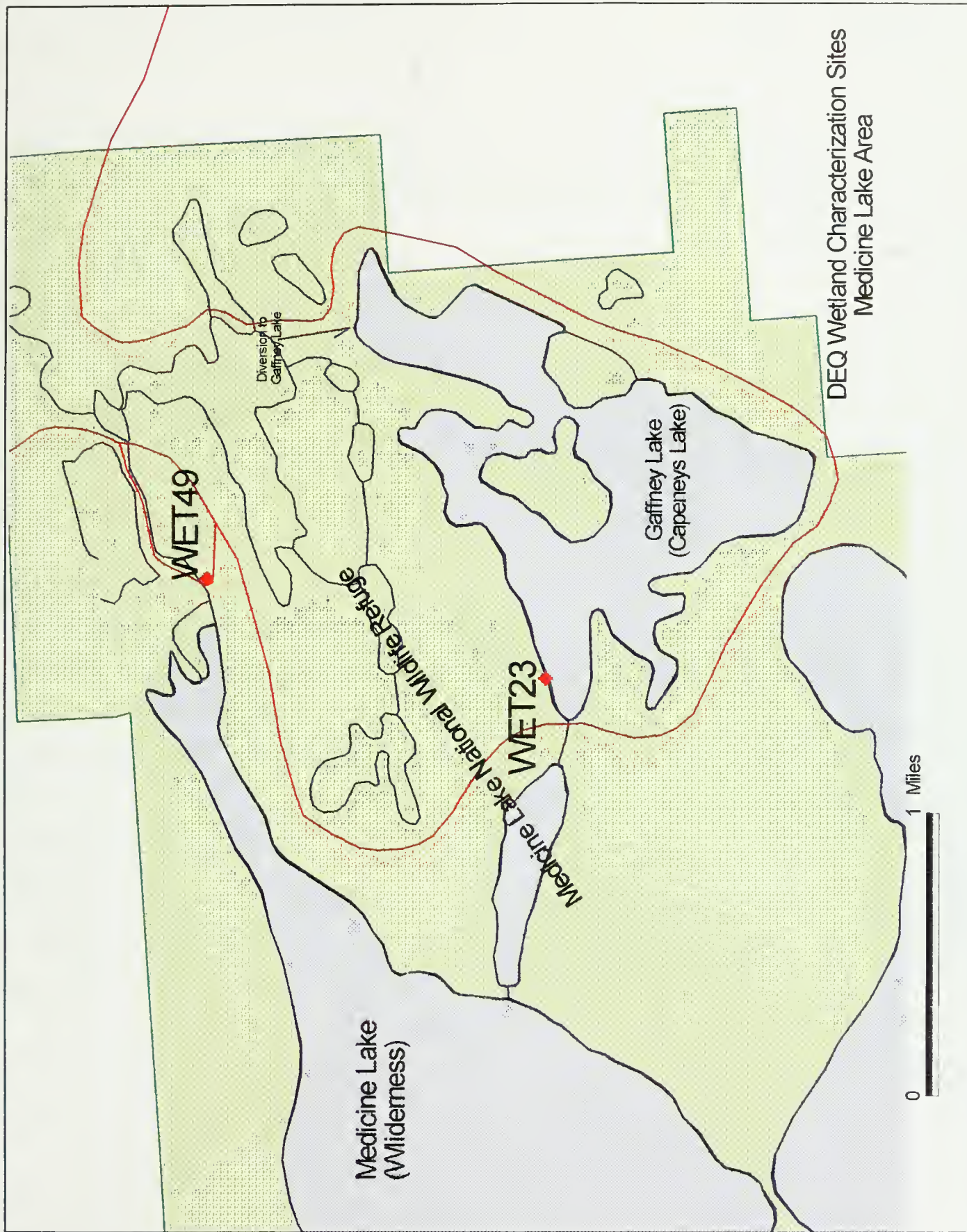
Inches Precipitation



Concentrations in Milligrams per liter







Wetland: GAFFNEY LAKE

Site Code: WET23

7.5 Minute Quad: CAPENEY'S LAKE

Lat: 48 28 40

Long: 104 20 0

Mean Annual Precipitation in Inches:	13.00
Mean Annual Potential Evaporation (Penman) in Inches:	37.00
'Net Precipitation' in Inches:	-24.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

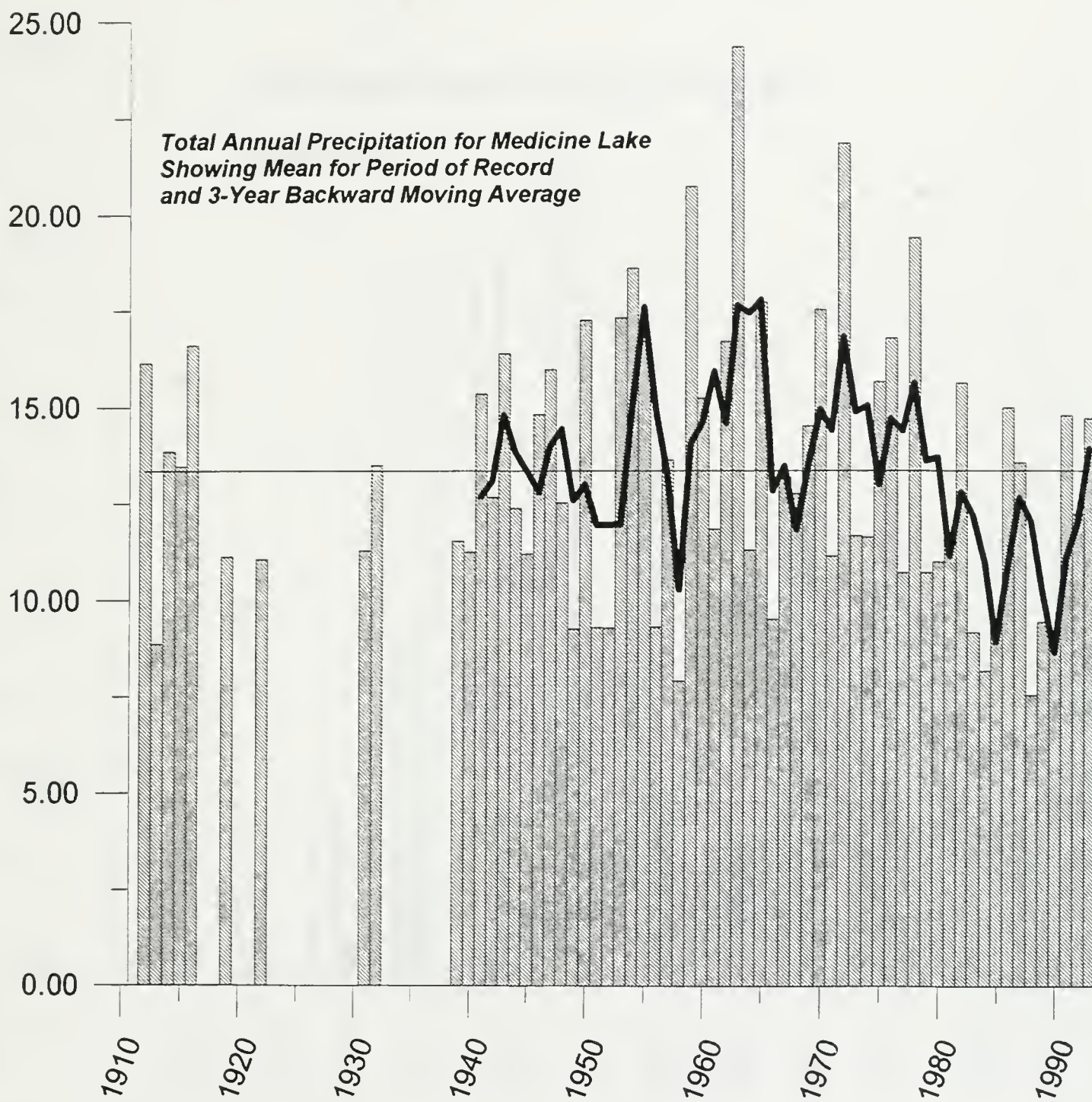
Site is artificially impounded.

Site does not have known significant water imports.

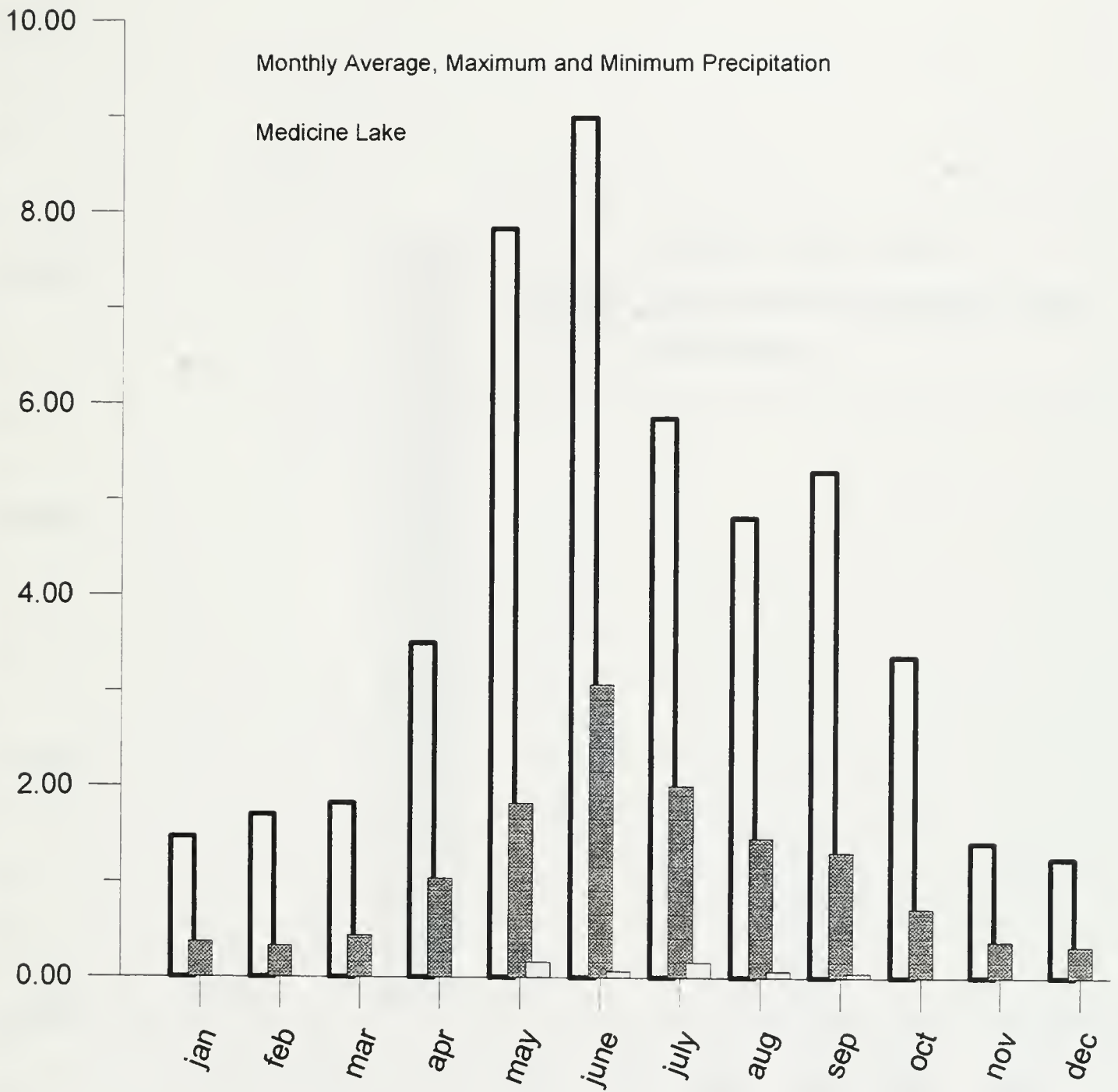
Mapped area of wetland:	650 acres
Area of contributing drainage basin:	292110 acres
Mapped elevation of wetland surface:	1937 ft
Maximum elevation within drainage basin:	2025 ft
Net relief of contributing basin:	88 ft

COE Hydrogeomorphic class:	FRINGE
Primary surficial geologic unit	112OTSH
Primary bedrock geologic unit	125FRUN

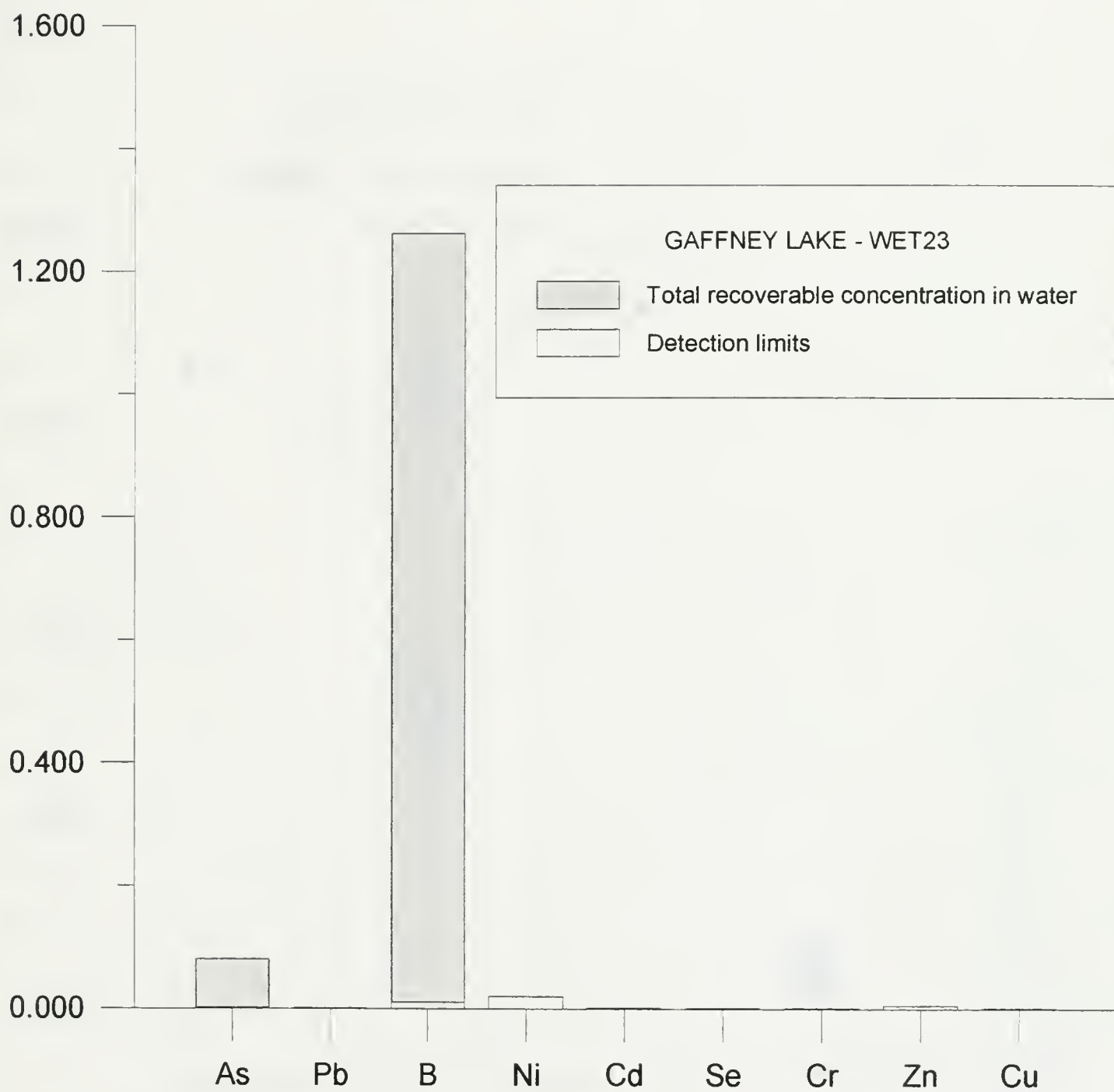
Total Annual Precipitation in Inches

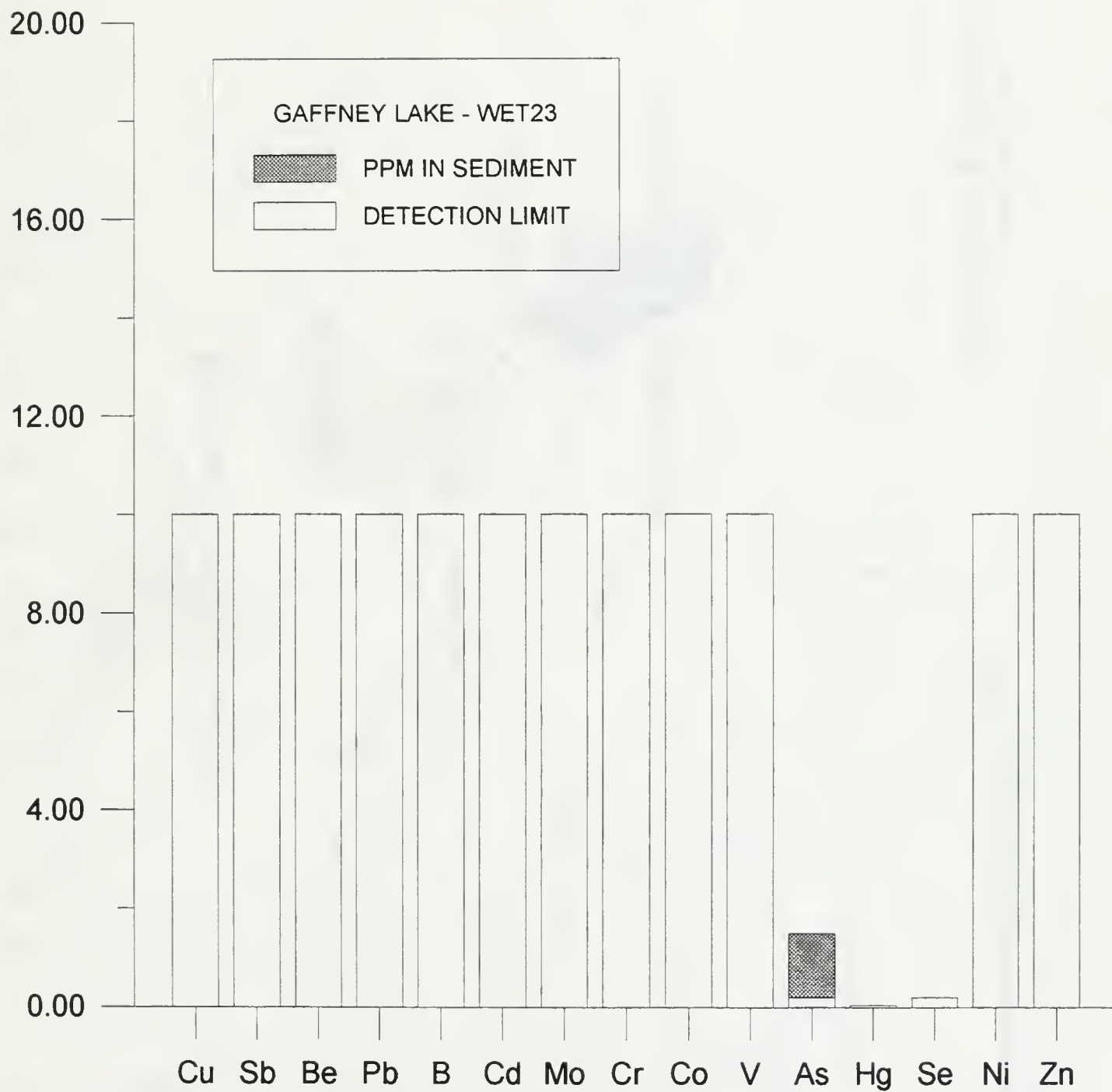


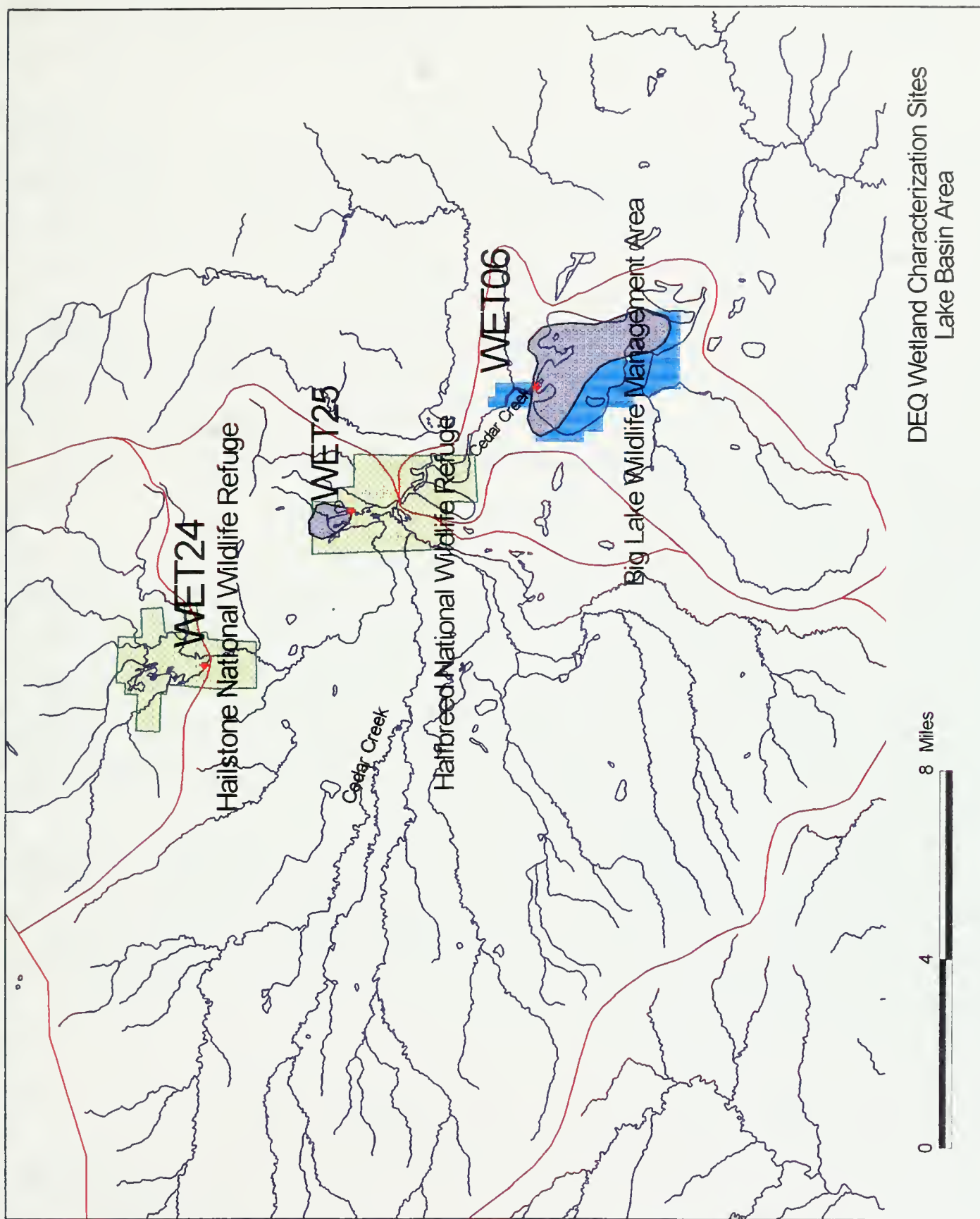
Inches Precipitation



Concentrations in Milligrams per liter







DEQ Wetland Characterization Sites
Lake Basin Area

Wetland: HAILSTONE NWR

Site Code: WET24

7.5 Minute Quad: HAILSTONE BASIN

Lat: 46 0 10

Long: 109 10 50

Mean Annual Precipitation in Inches:	13.00
Mean Annual Potential Evaporation (Penman) in Inches:	42.00
'Net Precipitation' in Inches:	-29.00

Site has a mapped surface inlet.

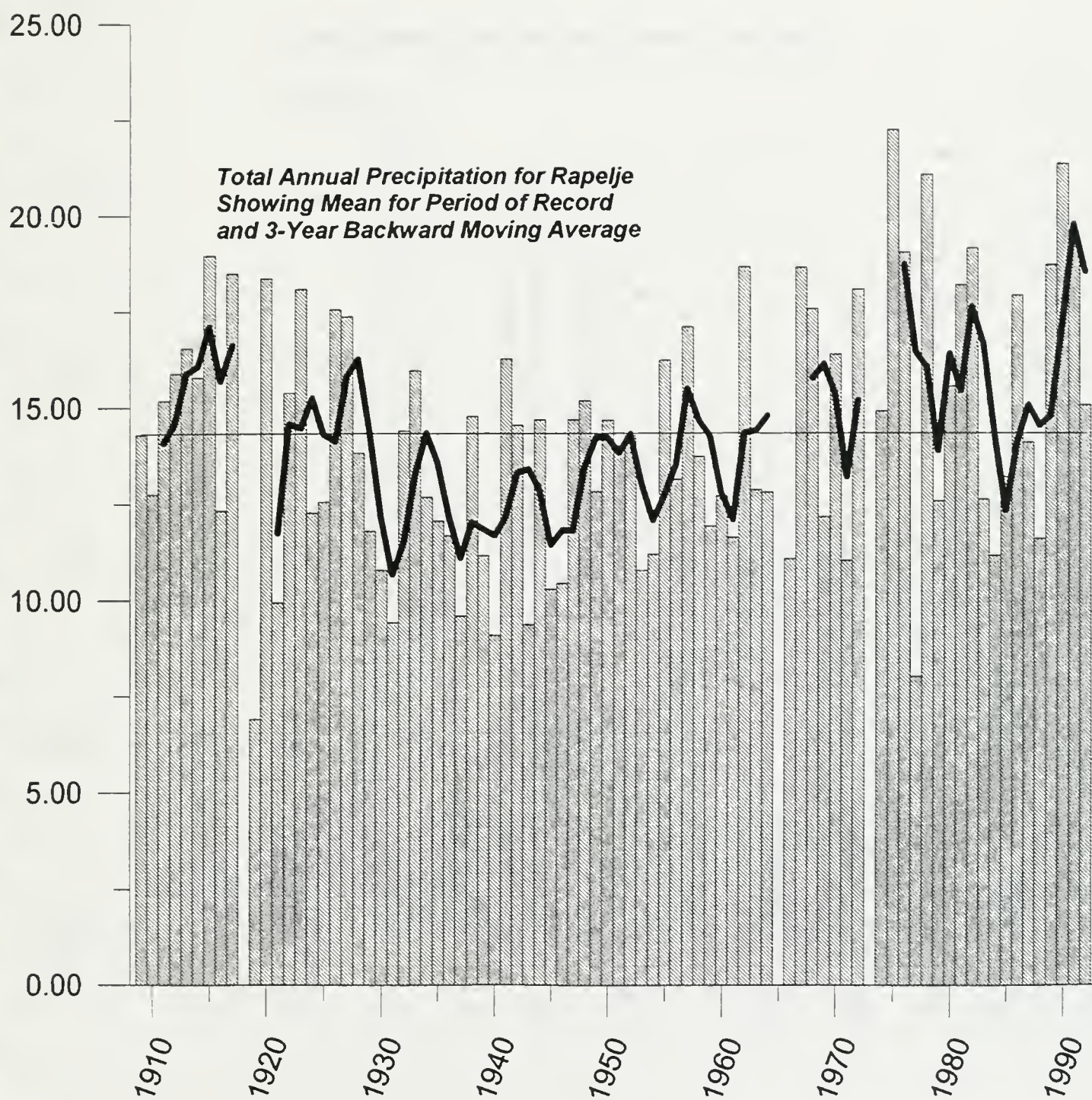
Site has a mapped surface outlet.

Site is artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland:	538 acres
Area of contributing drainage basin:	27860 acres
Mapped elevation of wetland surface:	3990 ft
Maximum elevation within drainage basin:	4728 ft
Net relief of contributing basin:	738 ft

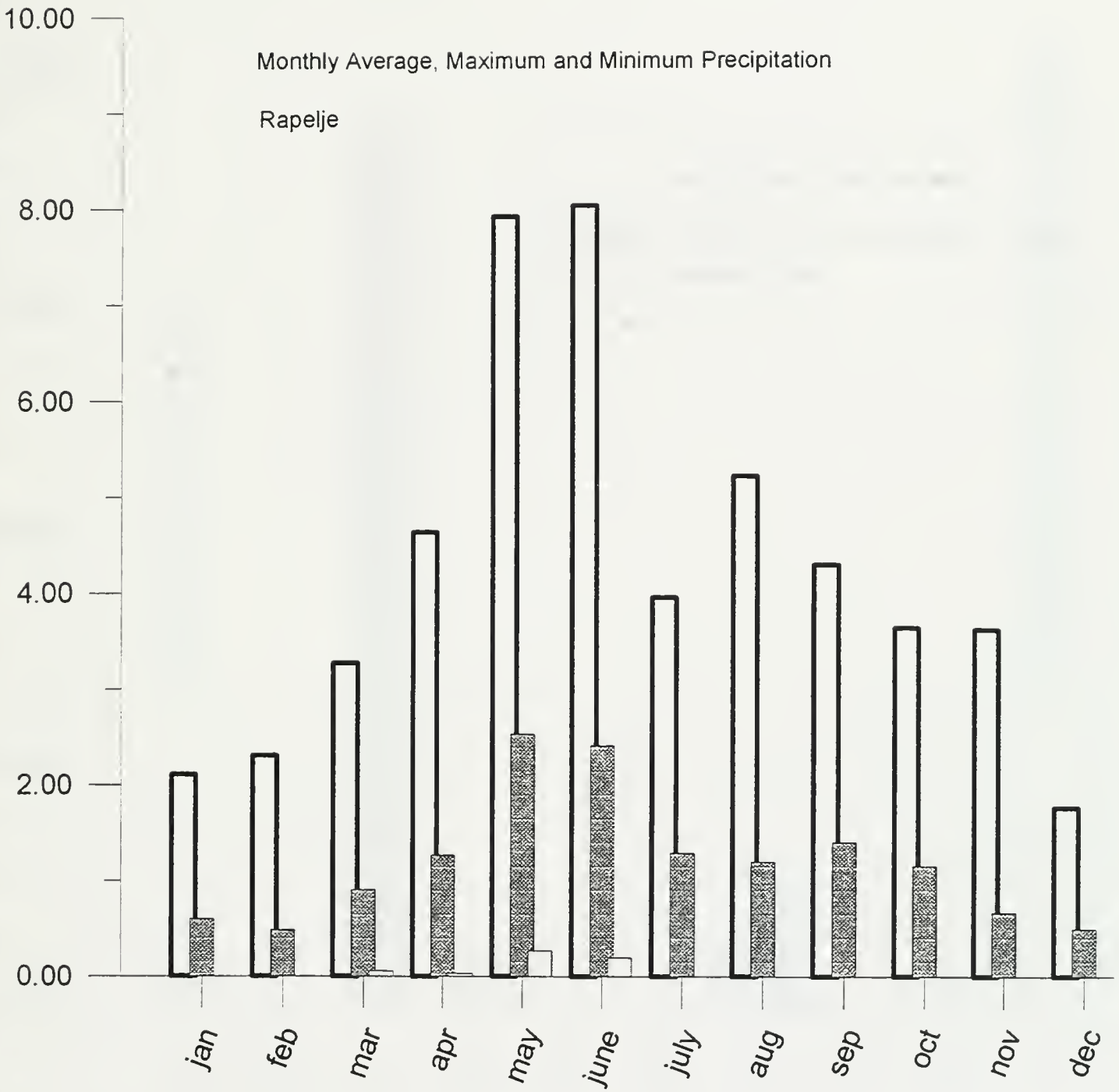
COE Hydrogeomorphic class:	FRINGE
Primary surficial geologic unit	110"LAC"
Primary bedrock geologic unit	210CRCS



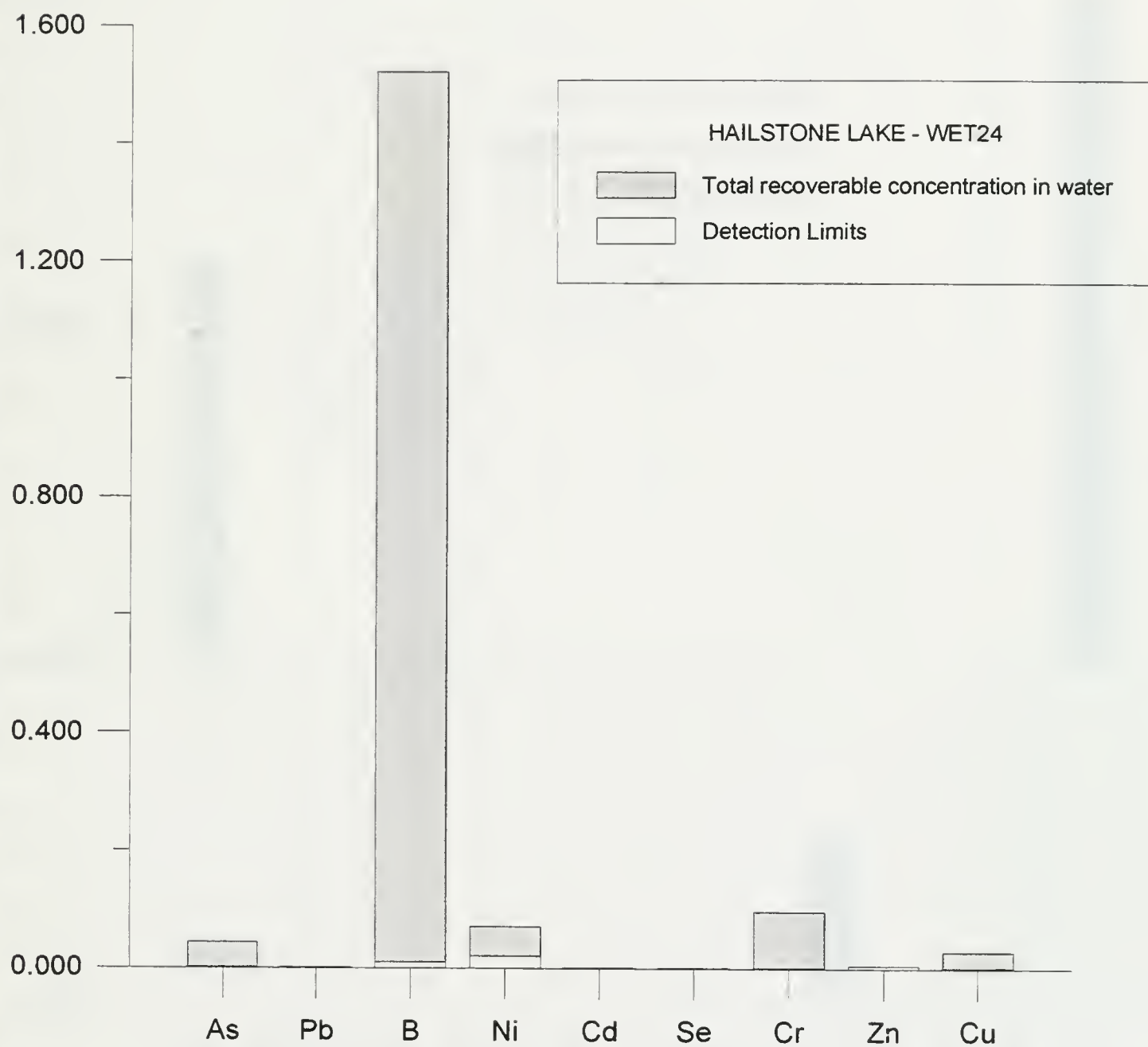
Monthly Average, Maximum and Minimum Precipitation

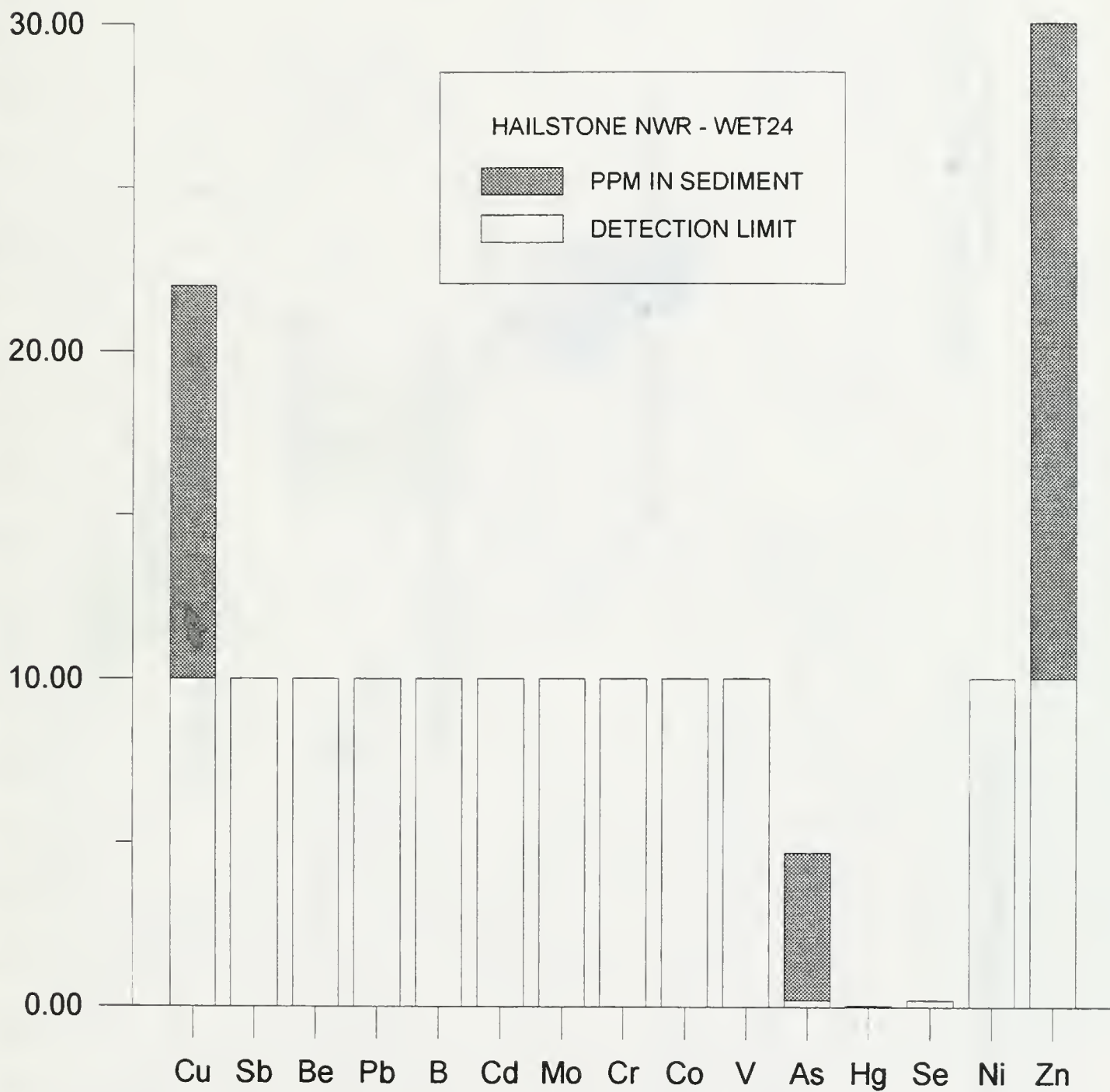
Rapelje

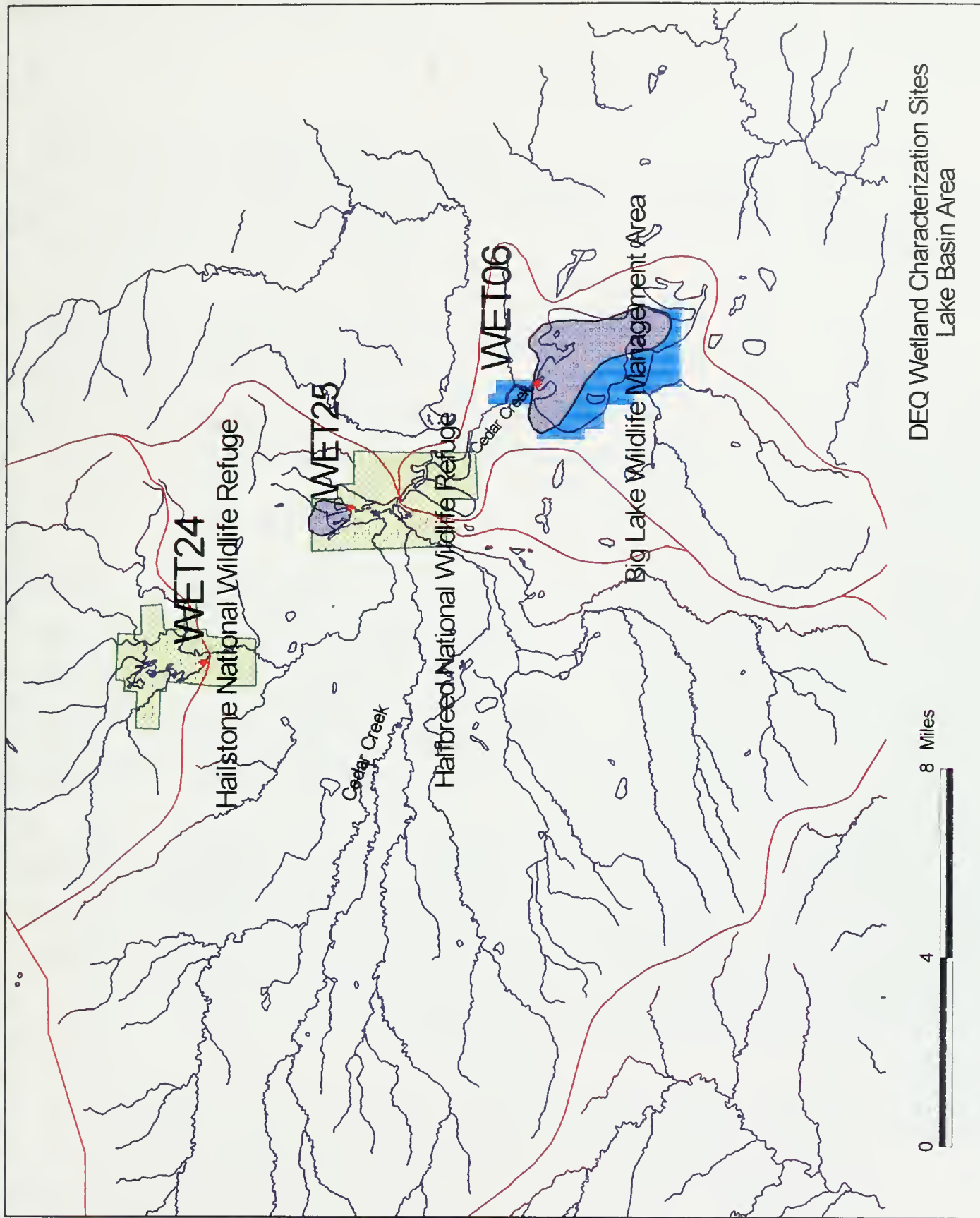
Inches Precipitation



Concentrations in Milligrams per liter







WET24

Hailstone National Wildlife Refuge

WET25

Halfbreed National Wildlife Refuge

WET06

Big Lake Wildlife Management Area

Cedar Creek

Cedar Creek

DEQ Wetland Characterization Sites
Lake Basin Area

0 4 8 Miles

Wetland: HALFBREED NWR

Site Code: WET25

7.5 Minute Quad: WHEAT BASIN

Lat: 45 57 30

Long: 109 6 45

Mean Annual Precipitation in Inches: 13.00

Mean Annual Potential Evaporation (Penman) in Inches: 41.00

'Net Precipitation' in Inches: -28.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 278 acres

Area of contributing drainage basin: 141960 acres

Mapped elevation of wetland surface: 3935 ft

Maximum elevation within drainage basin: 5325 ft

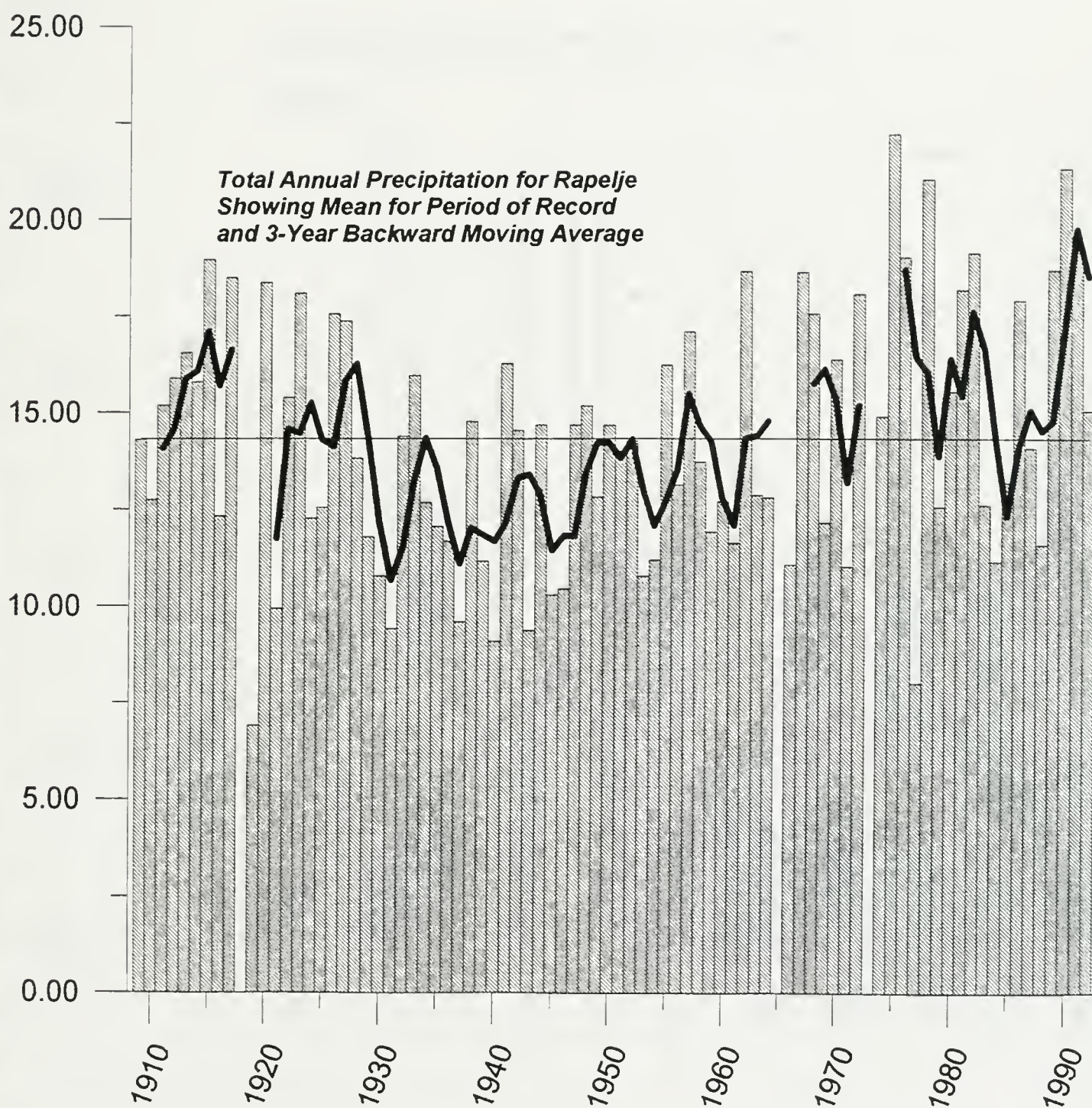
Net relief of contributing basin: 1390 ft

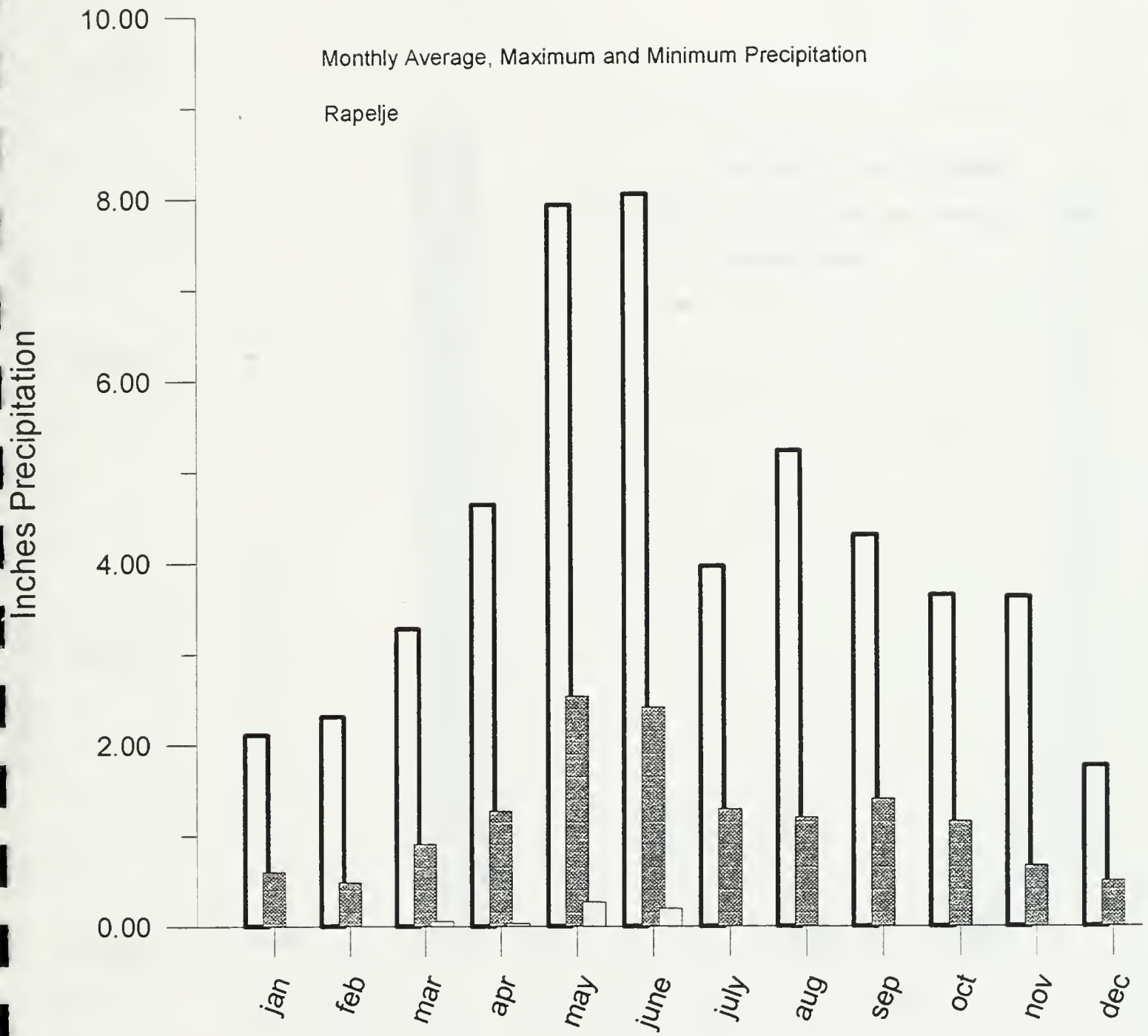
COE Hydrogeomorphic class: FRINGE

Primary surficial geologic unit 110"LAC"

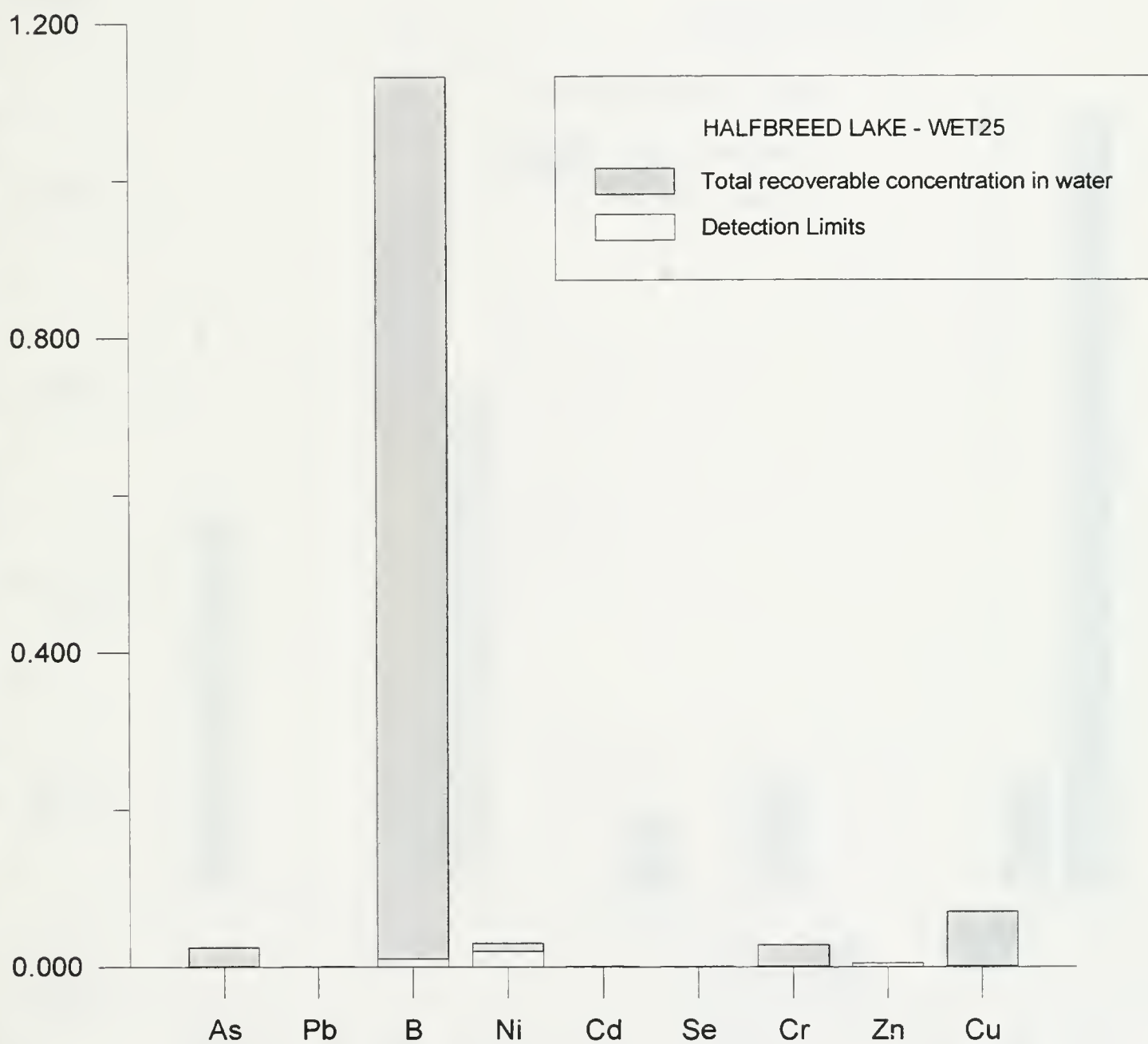
Primary bedrock geologic unit 210CRCS

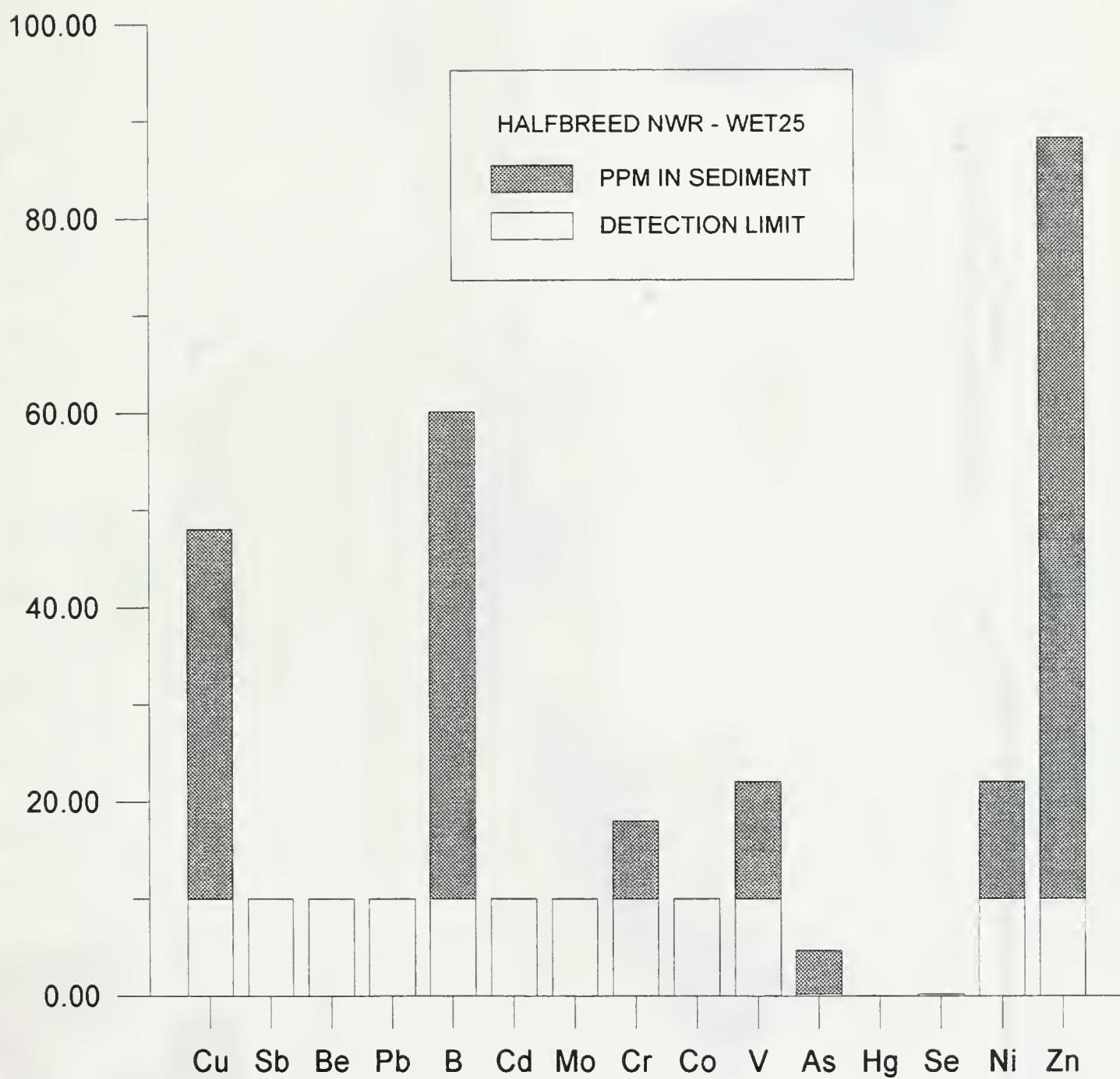
Annual Precipitation in Inches

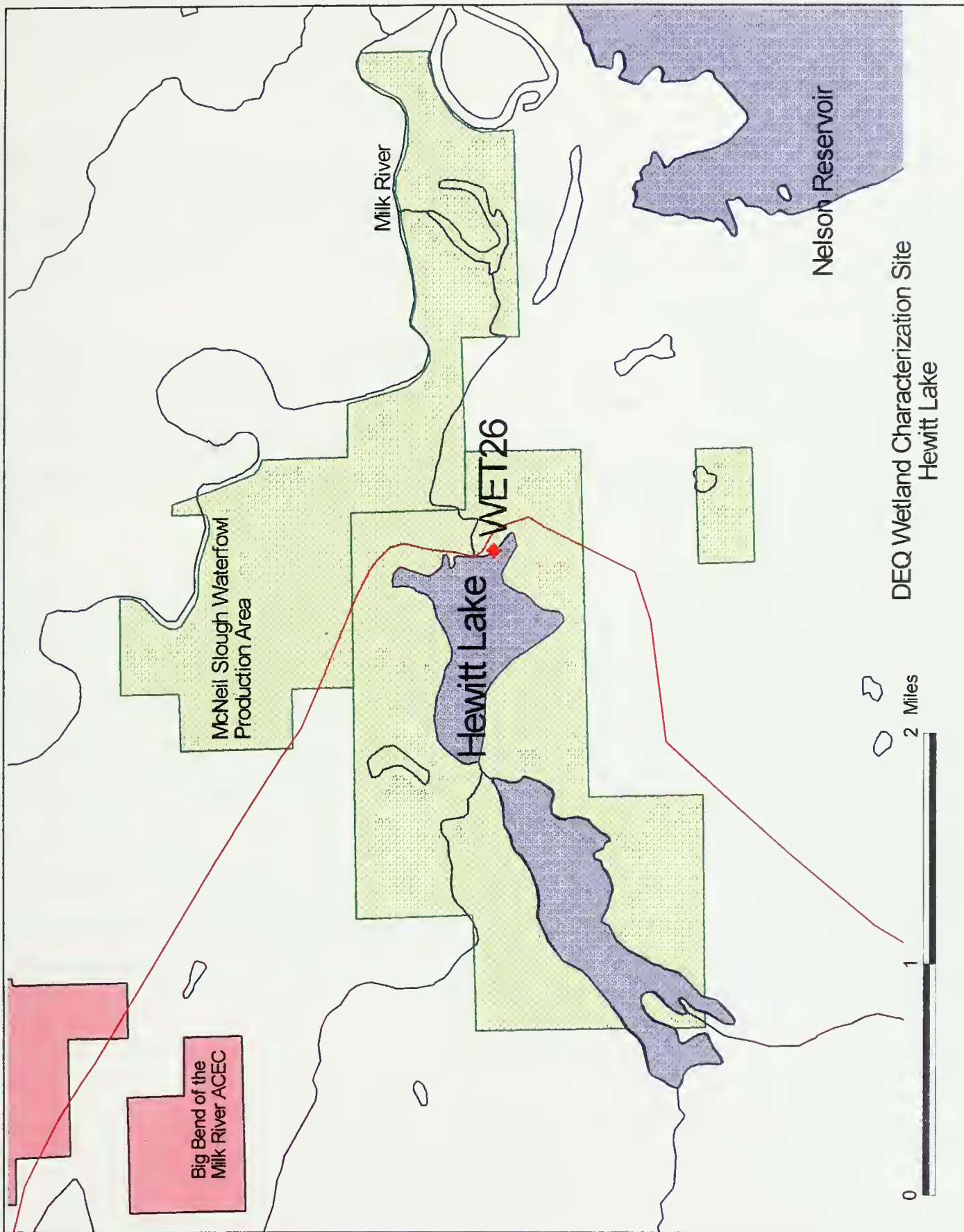




Concentrations in Milligrams per liter







Wetland: HEWITT LAKE NWR

Site Code: WET26

7.5 Minute Quad: HEWITT LAKE

Lat: 48 32 15

Long: 107 34 55

Mean Annual Precipitation in Inches:	11.00
Mean Annual Potential Evaporation (Penman) in Inches:	39.00
'Net Precipitation' in Inches:	-28.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

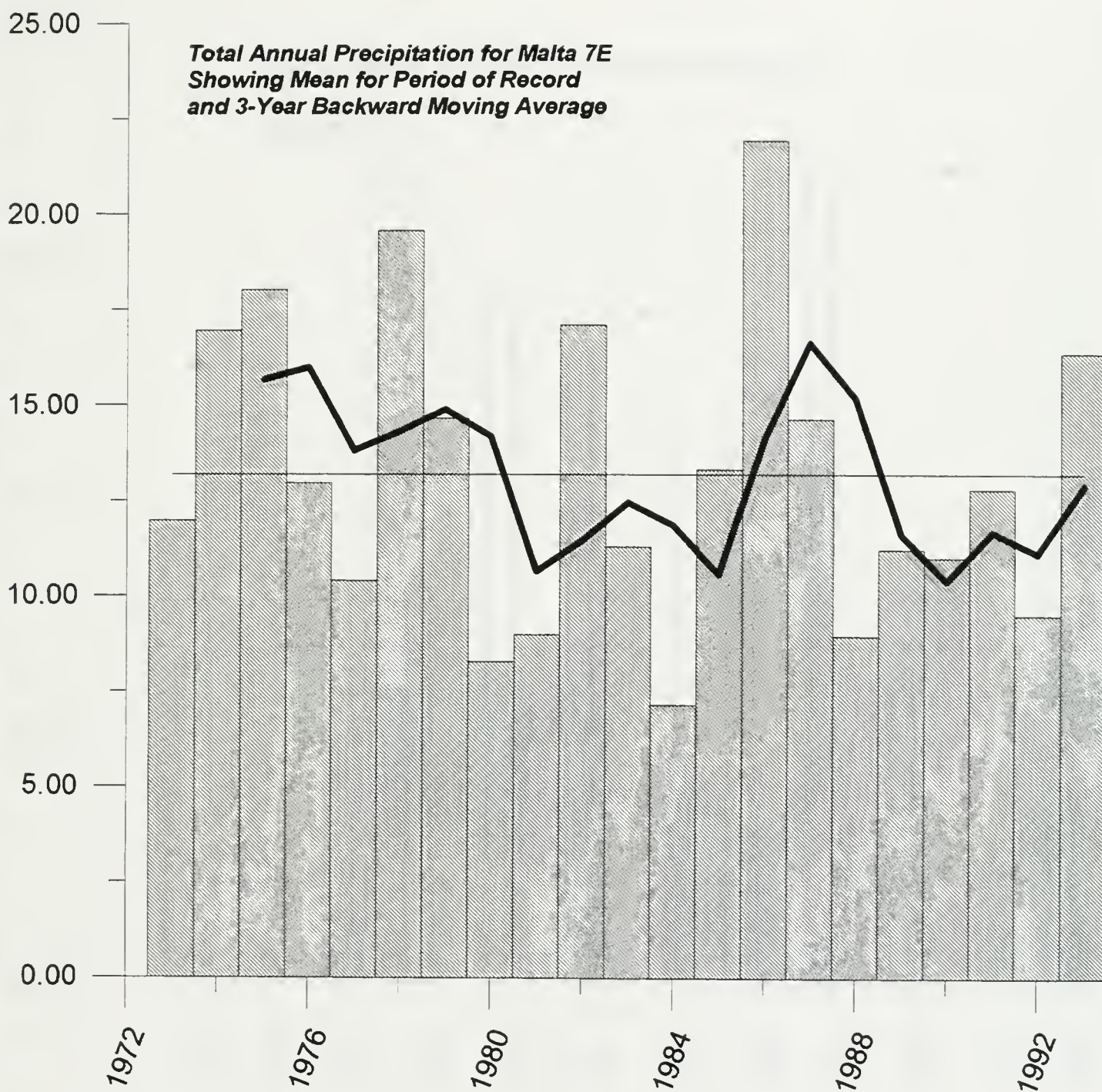
Site is artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland:	180 acres
Area of contributing drainage basin:	12400 acres
Mapped elevation of wetland surface:	2197 ft
Maximum elevation within drainage basin:	2480 ft
Net relief of contributing basin:	283 ft

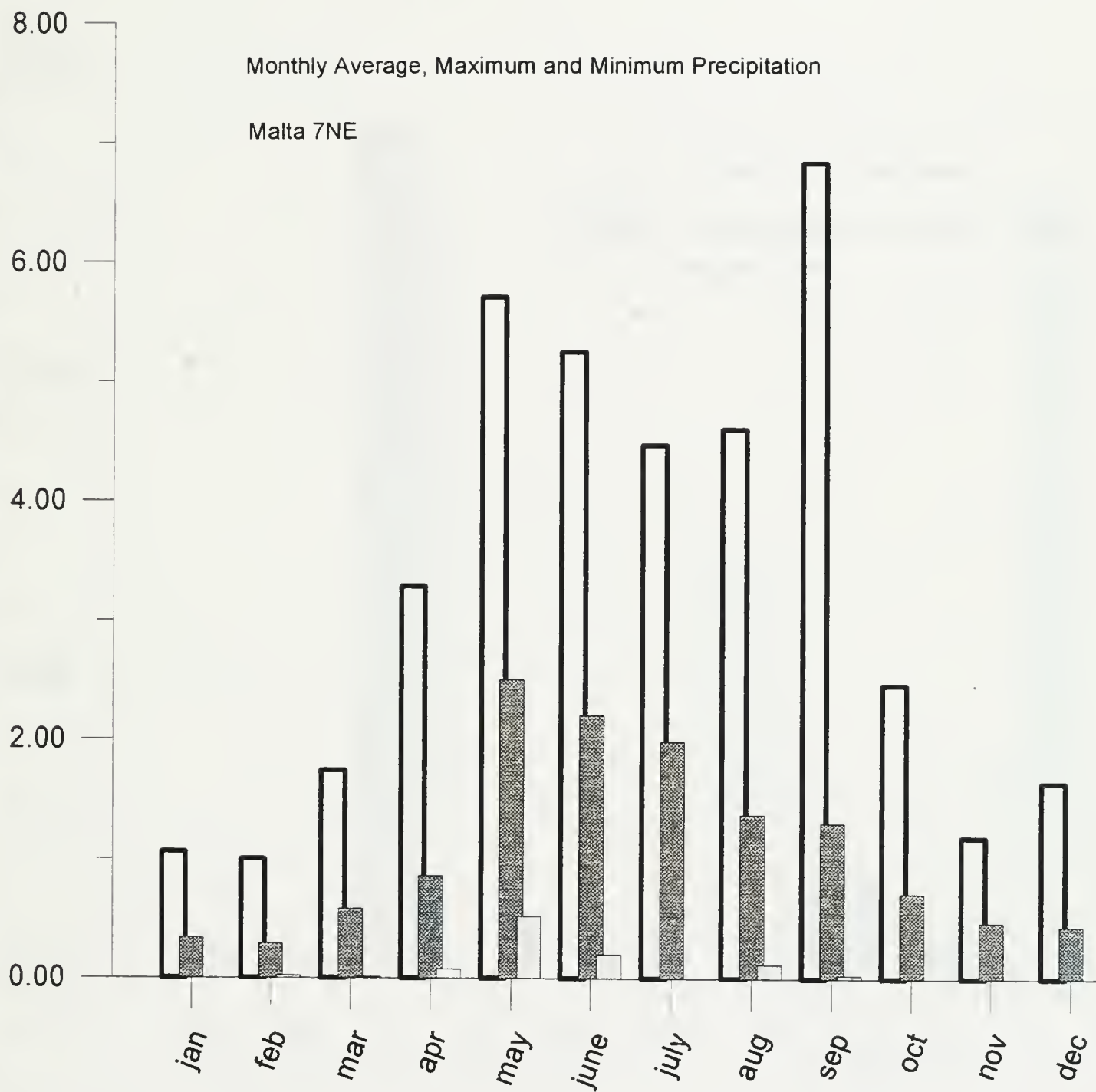
COE Hydrogeomorphic class:	FRINGE
Primary surficial geologic unit	112DRFT
Primary bedrock geologic unit	211CLGG

Annual Precipitation in Inches

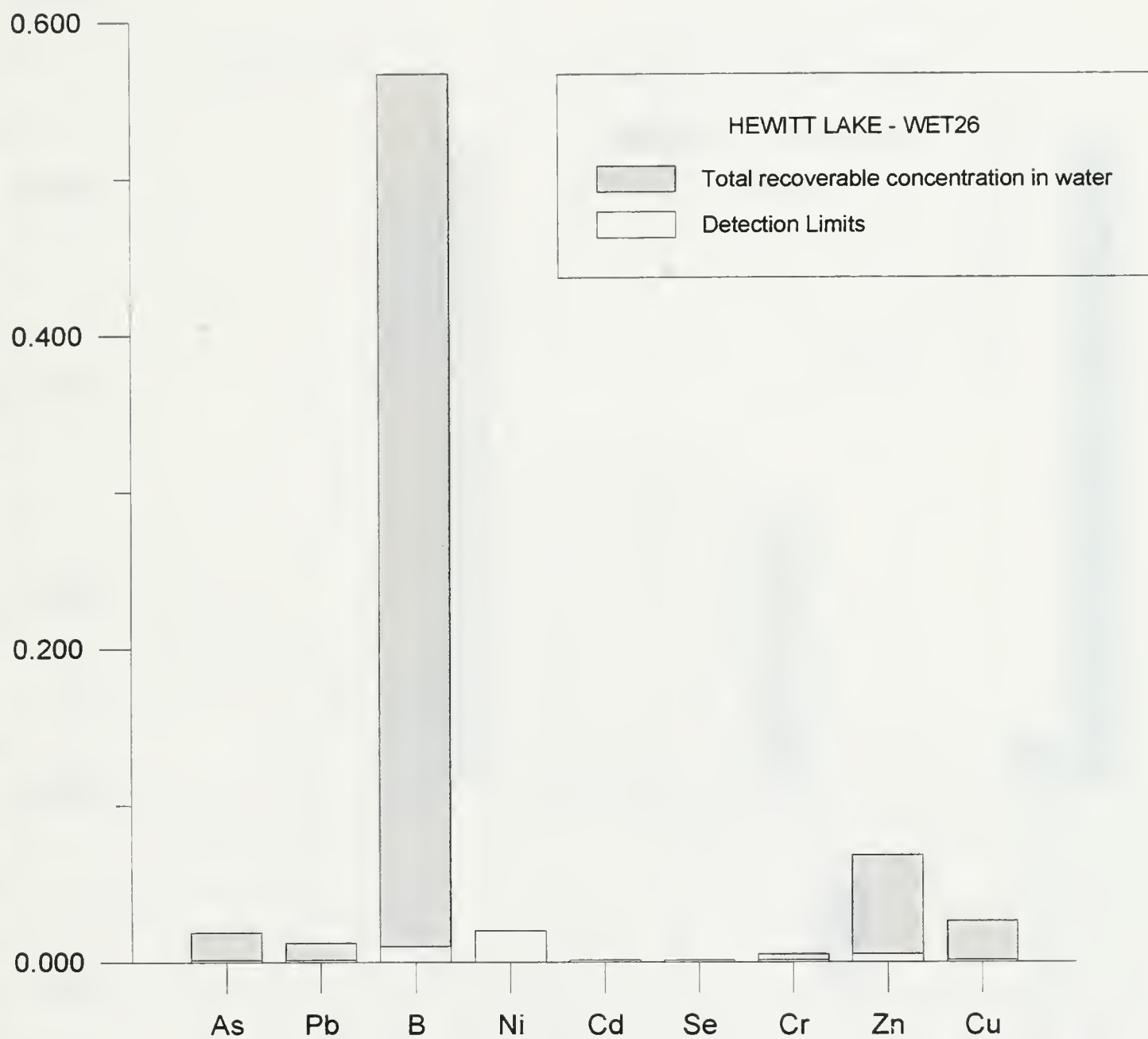


Monthly Average, Maximum and Minimum Precipitation

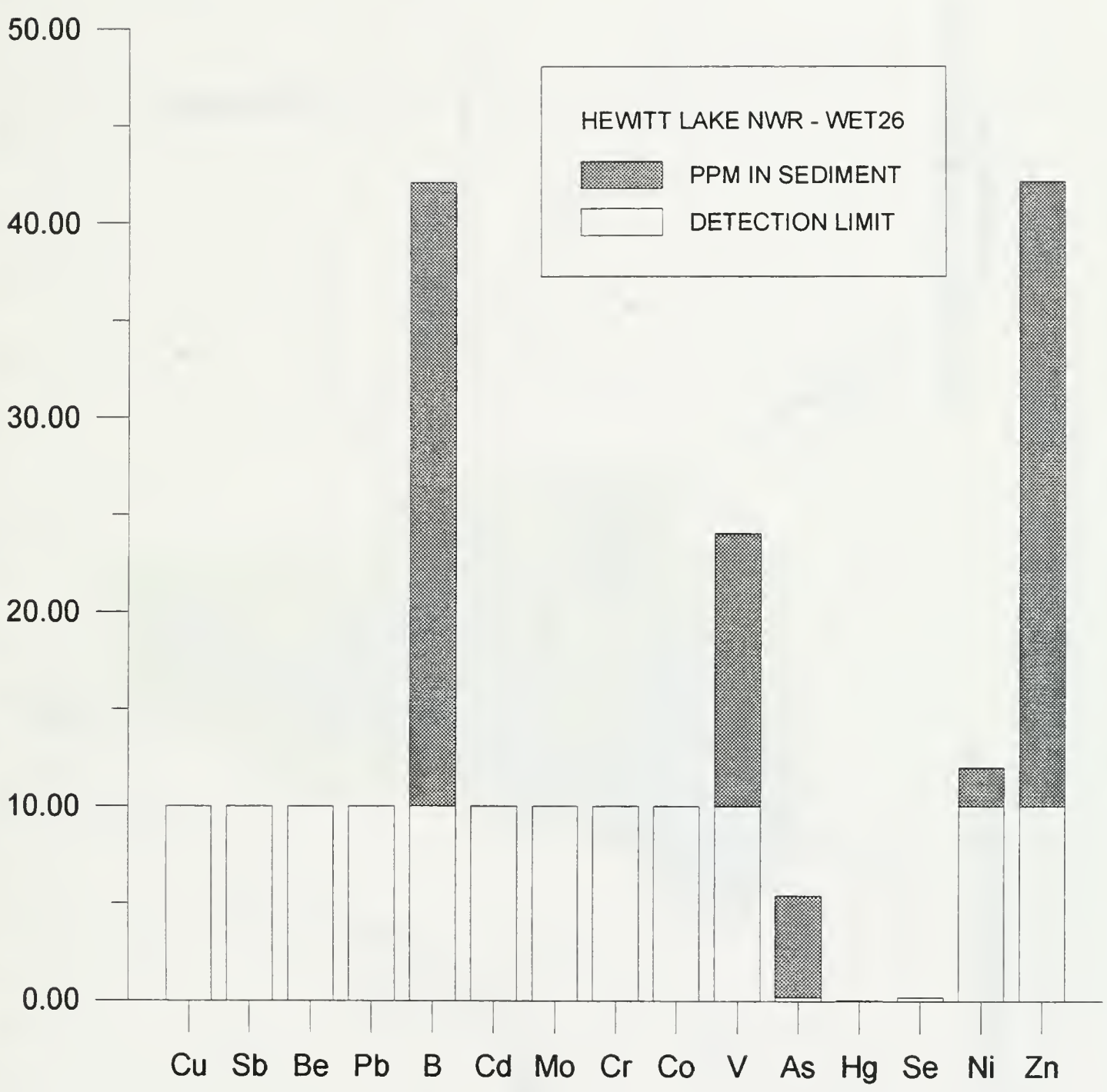
Malta 7NE

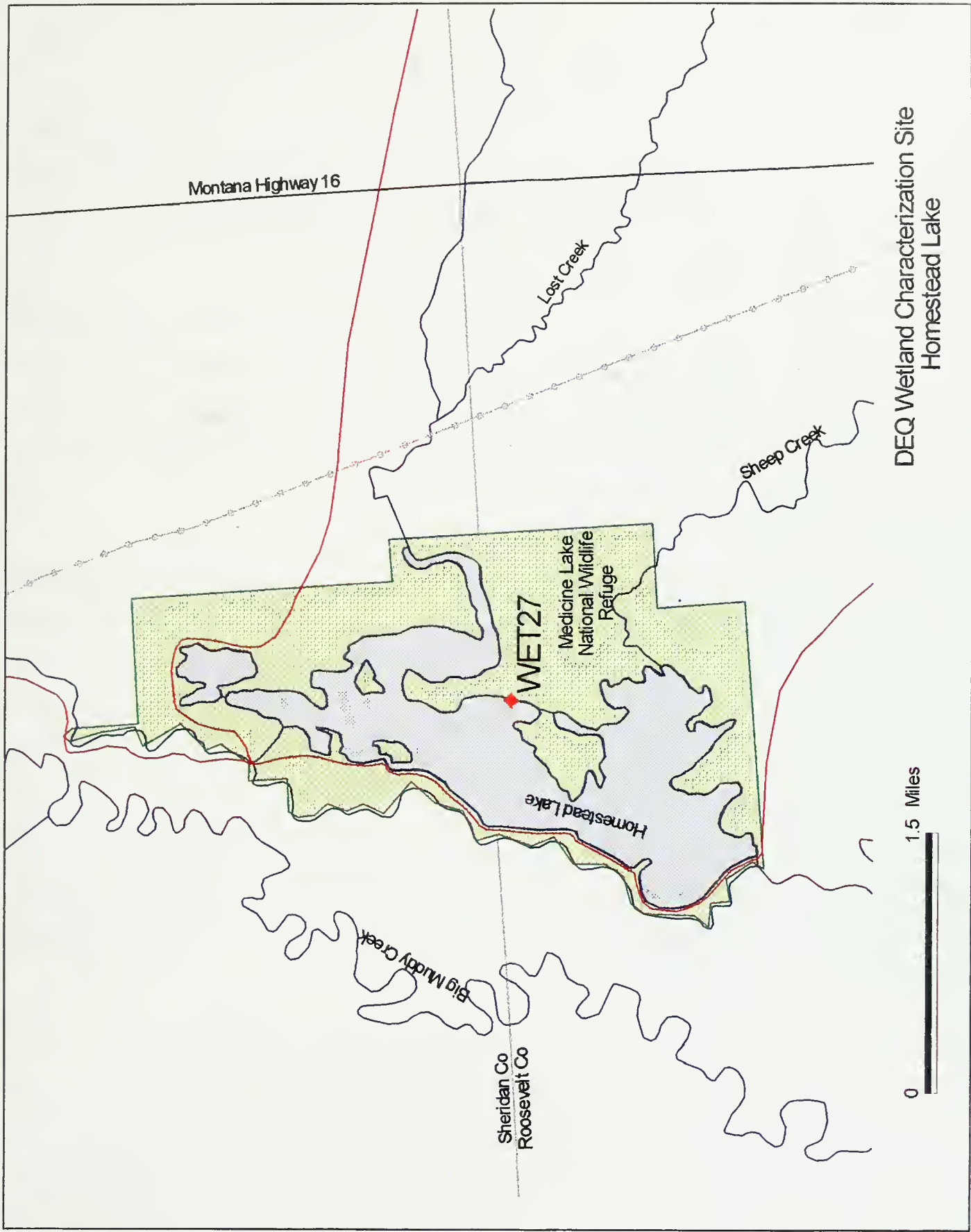


Concentrations in Milligrams per liter



HNO3 - Extractable Sediment Concentrations in PPM





DEQ Wetland Characterization Site
Homestead Lake

0 1.5 Miles

Wetland: HOMESTEAD LAKE

Site Code: WET27

7.5 Minute Quad: HOMESTEAD

Lat: 48 23 15

Long: 104 33 15

Mean Annual Precipitation in Inches: 13.00

Mean Annual Potential Evaporation (Penman) in Inches: 38.00

'Net Precipitation' in Inches: -25.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is artificially impounded.

Site has significant water imports.

Mapped area of wetland: 1240 acres

Area of contributing drainage basin: 64500 acres

Mapped elevation of wetland surface: 1935 ft

Maximum elevation within drainage basin: 2460 ft

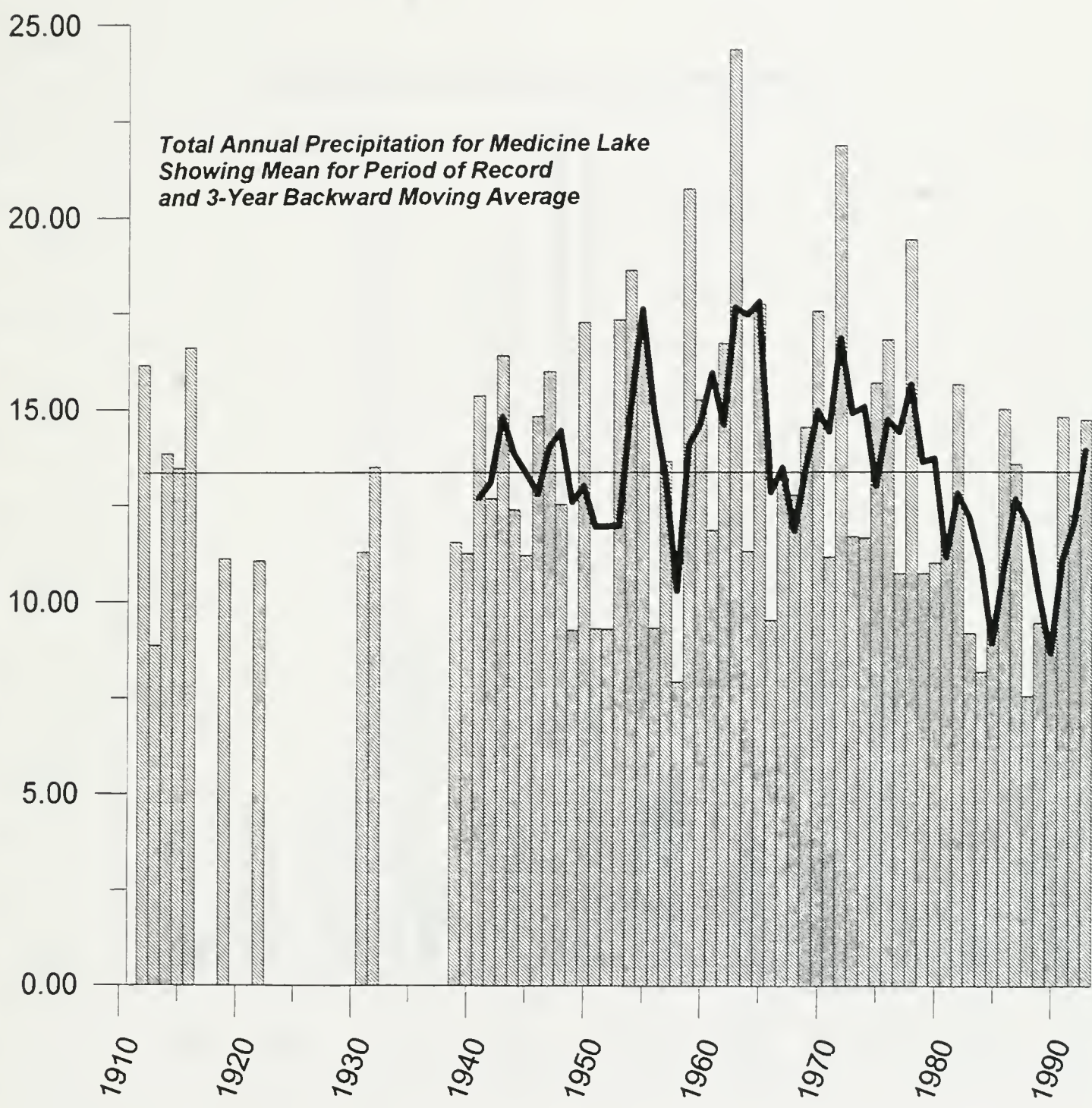
Net relief of contributing basin: 525 ft

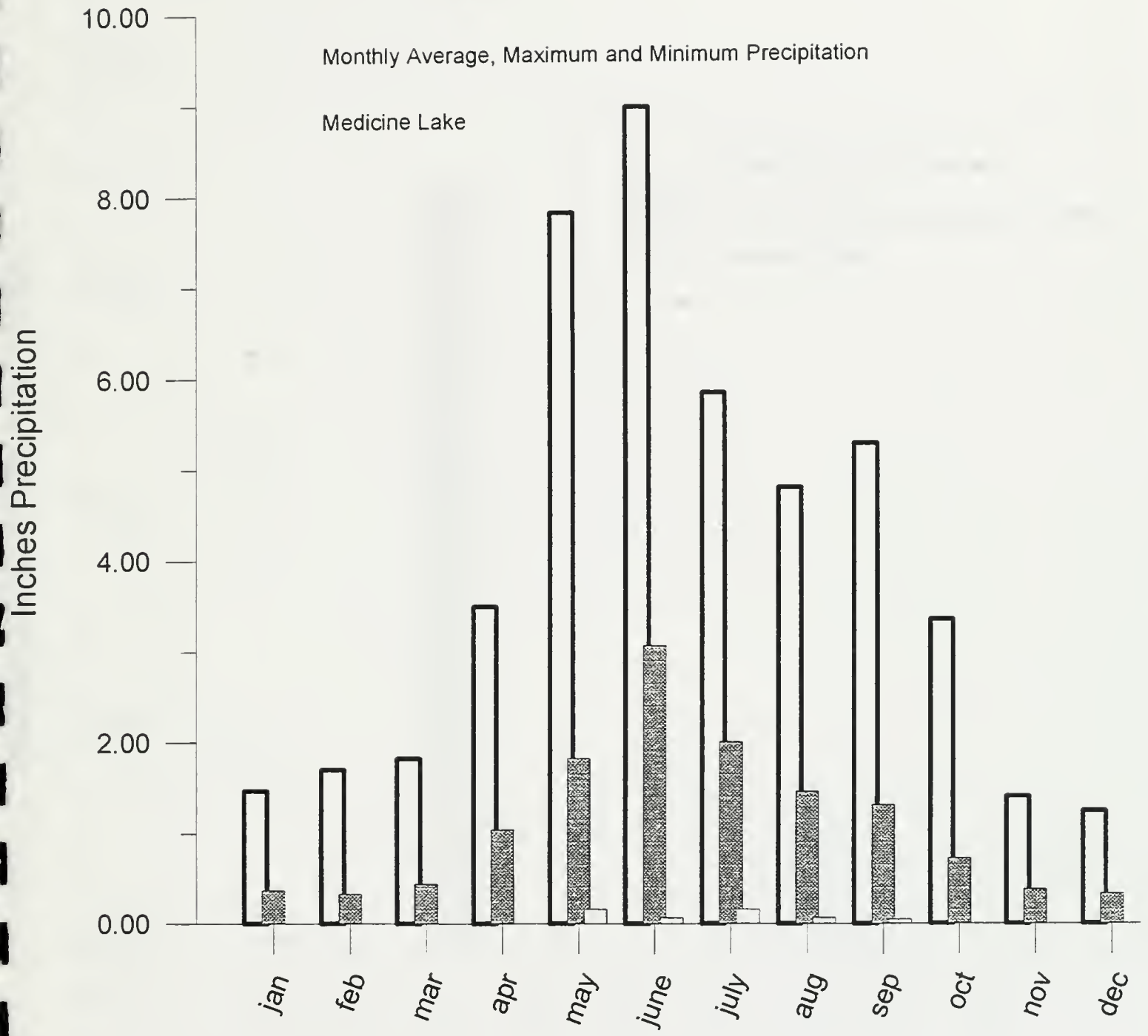
COE Hydrogeomorphic class: FRINGE

Primary surficial geologic unit 112OTSH

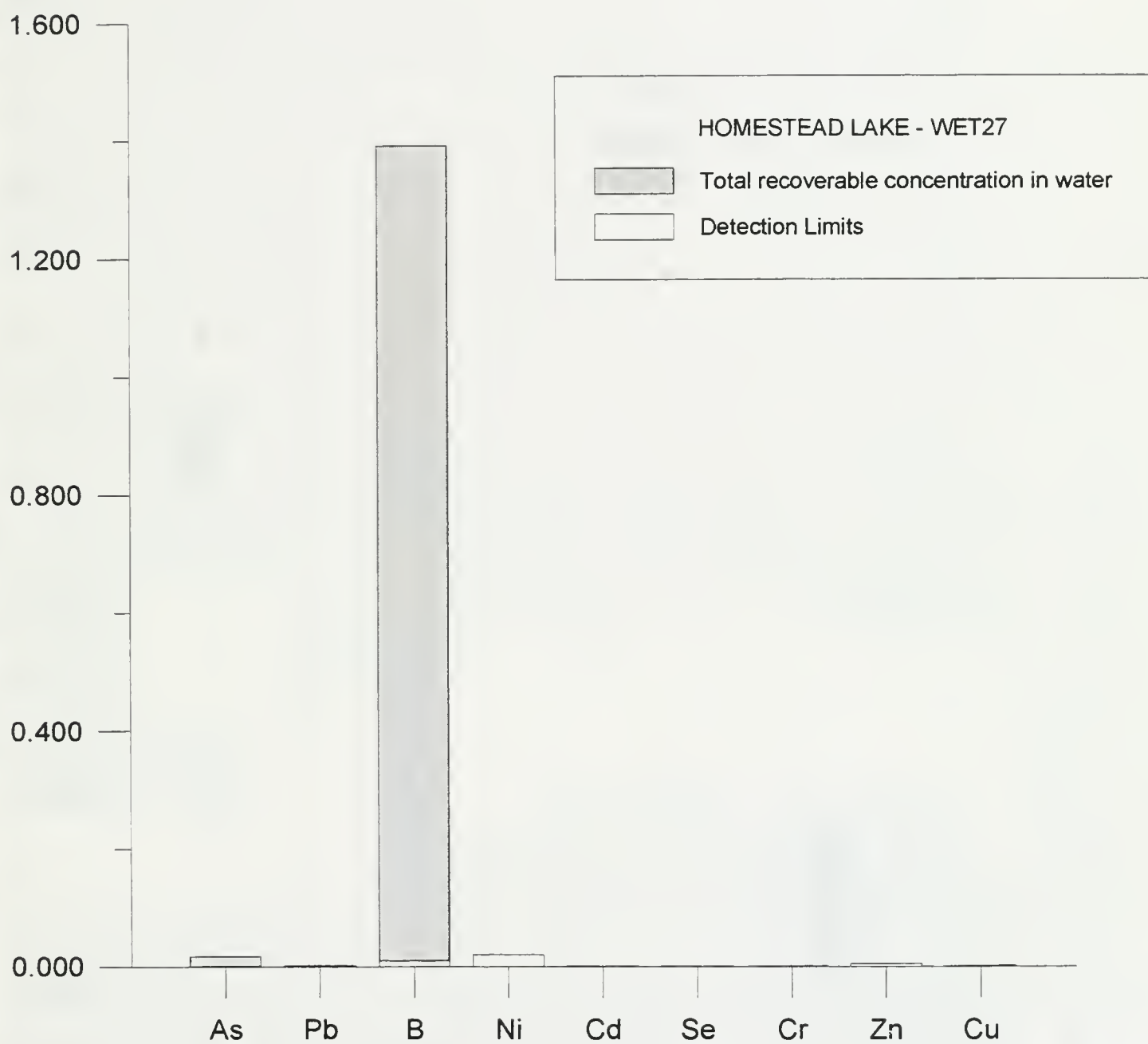
Primary bedrock geologic unit 125FRUN

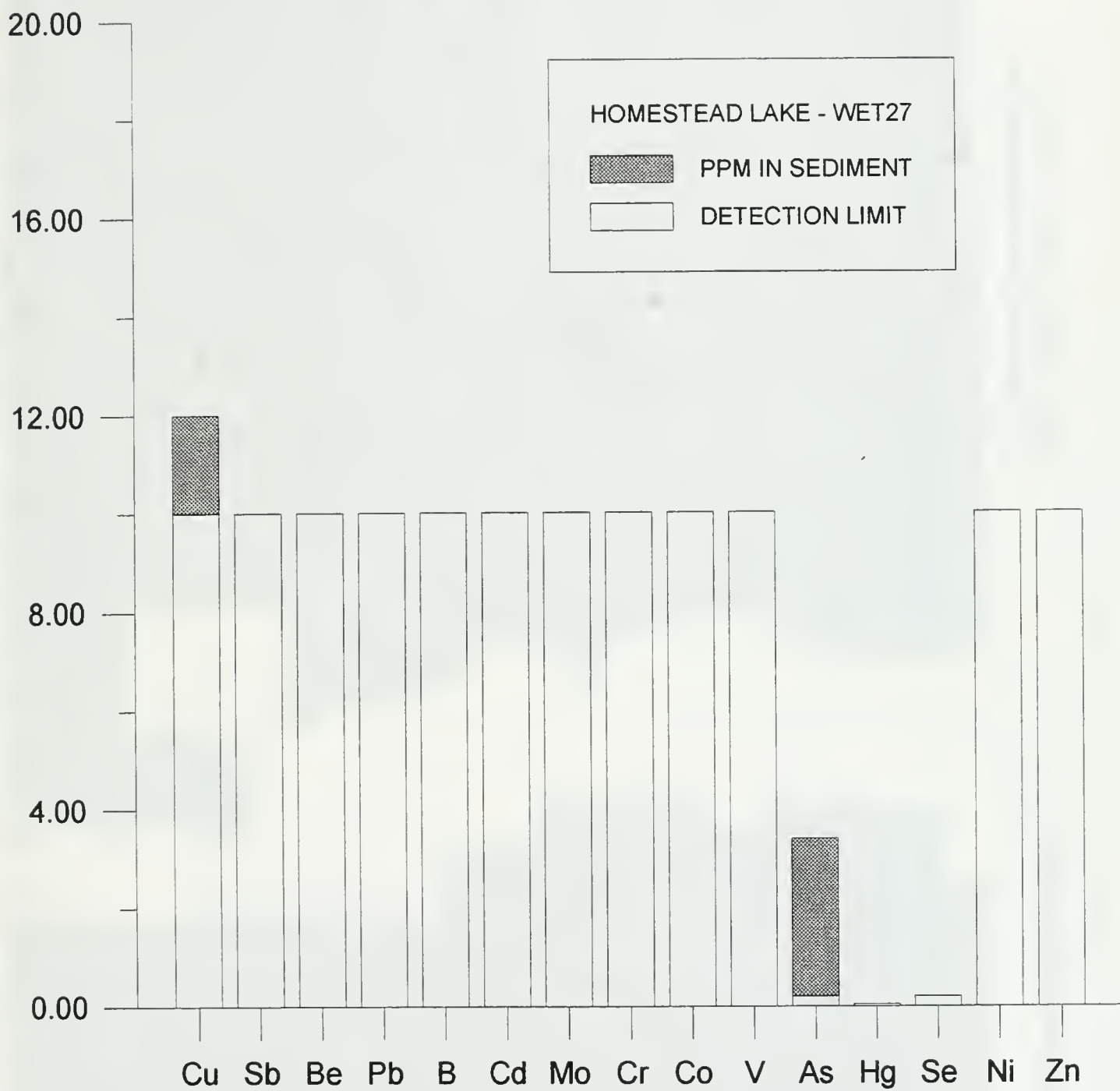
Total Annual Precipitation in Inches





Concentrations in Milligrams per liter







DEQ Wetland Characterization Site
Hoskins Lake Research Natural Area

Wetland: HOSKINS LAKE RNA

Site Code: WET28

7.5 Minute Quad: BONNET TOP

Lat: 48 53 40

Long: 115 38 10

Mean Annual Precipitation in Inches: 35.00

Mean Annual Potential Evaporation (Penman) in Inches: 28.00

'Net Precipitation' in Inches: 7.00

Site does not have a mapped surface inlet.

Site has a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 8 acres

Area of contributing drainage basin: 430 acres

Mapped elevation of wetland surface: 3650 ft

Maximum elevation within drainage basin: 4725 ft

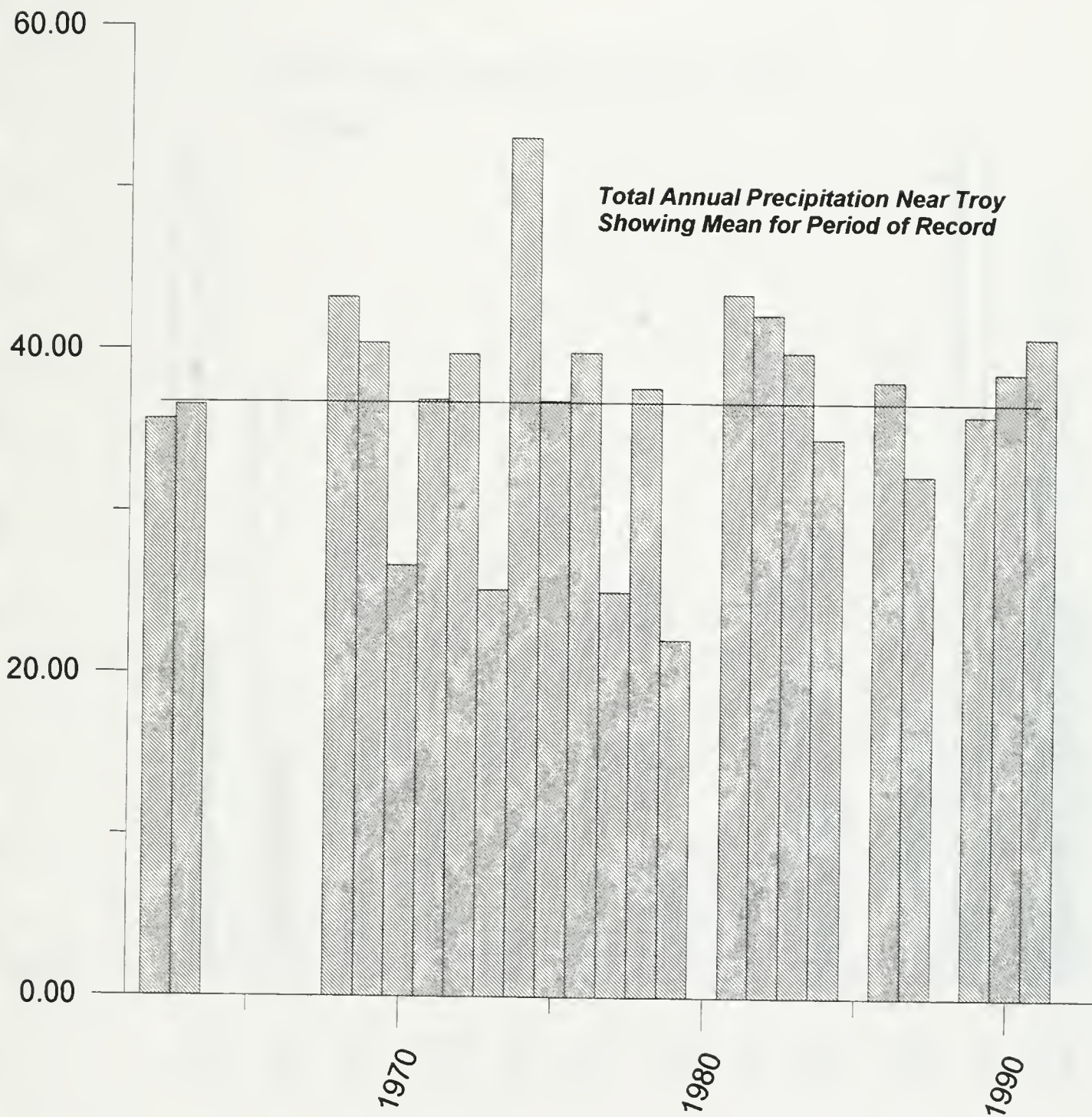
Net relief of contributing basin: 1075 ft

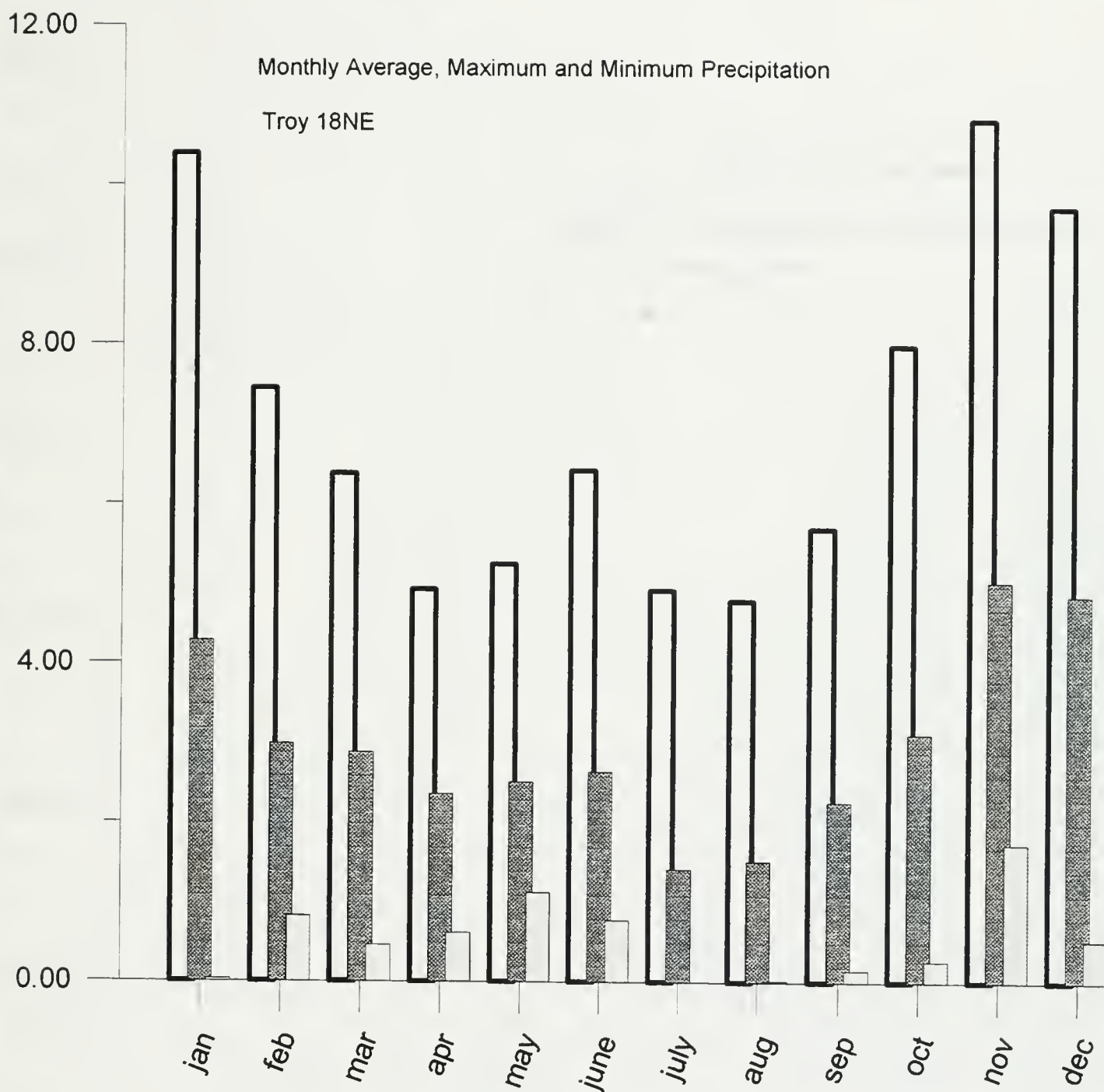
COE Hydrogeomorphic class: DEPRESSIONAL

Primary surficial geologic unit 112DRFT

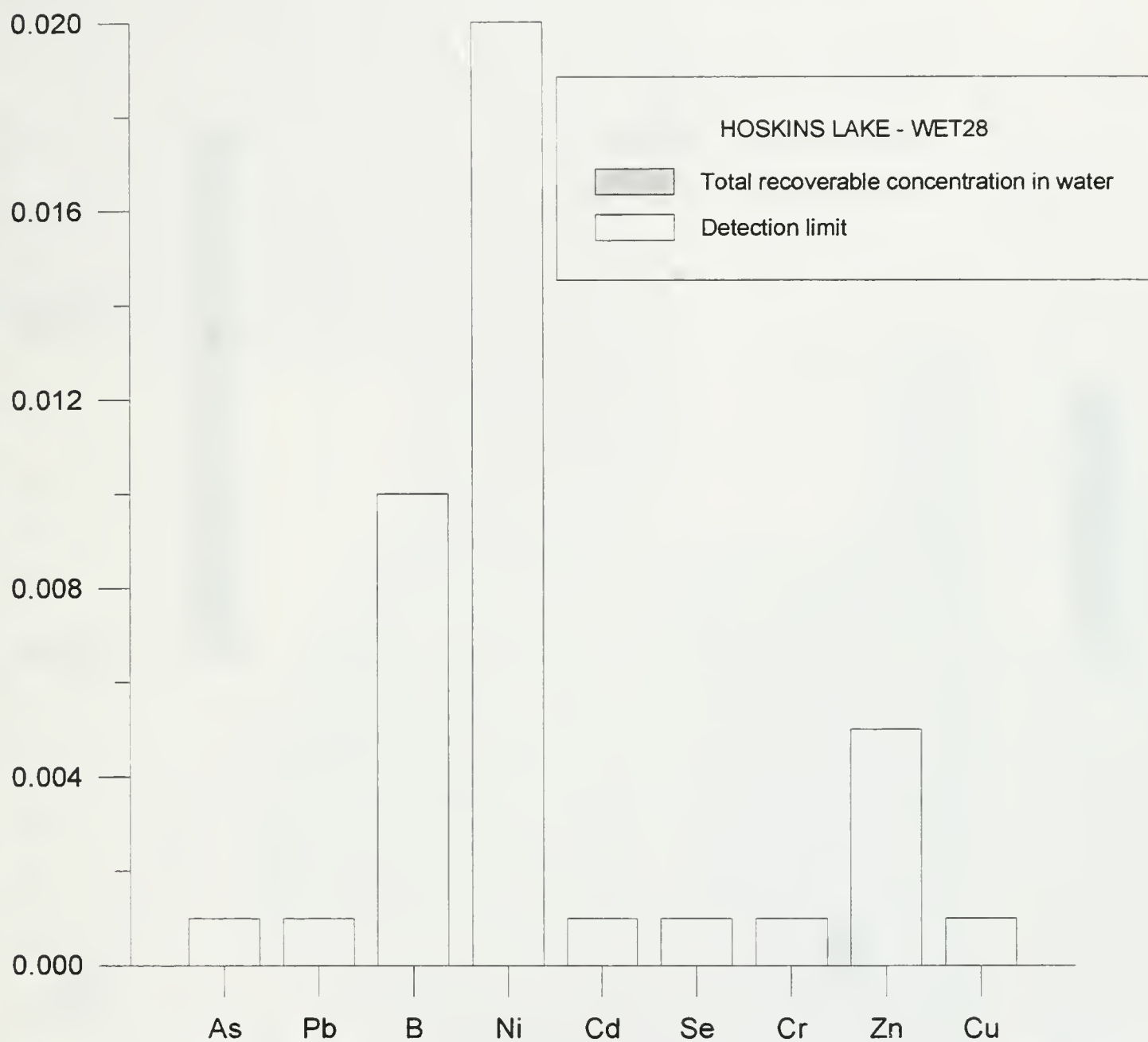
Primary bedrock geologic unit 400WLLC

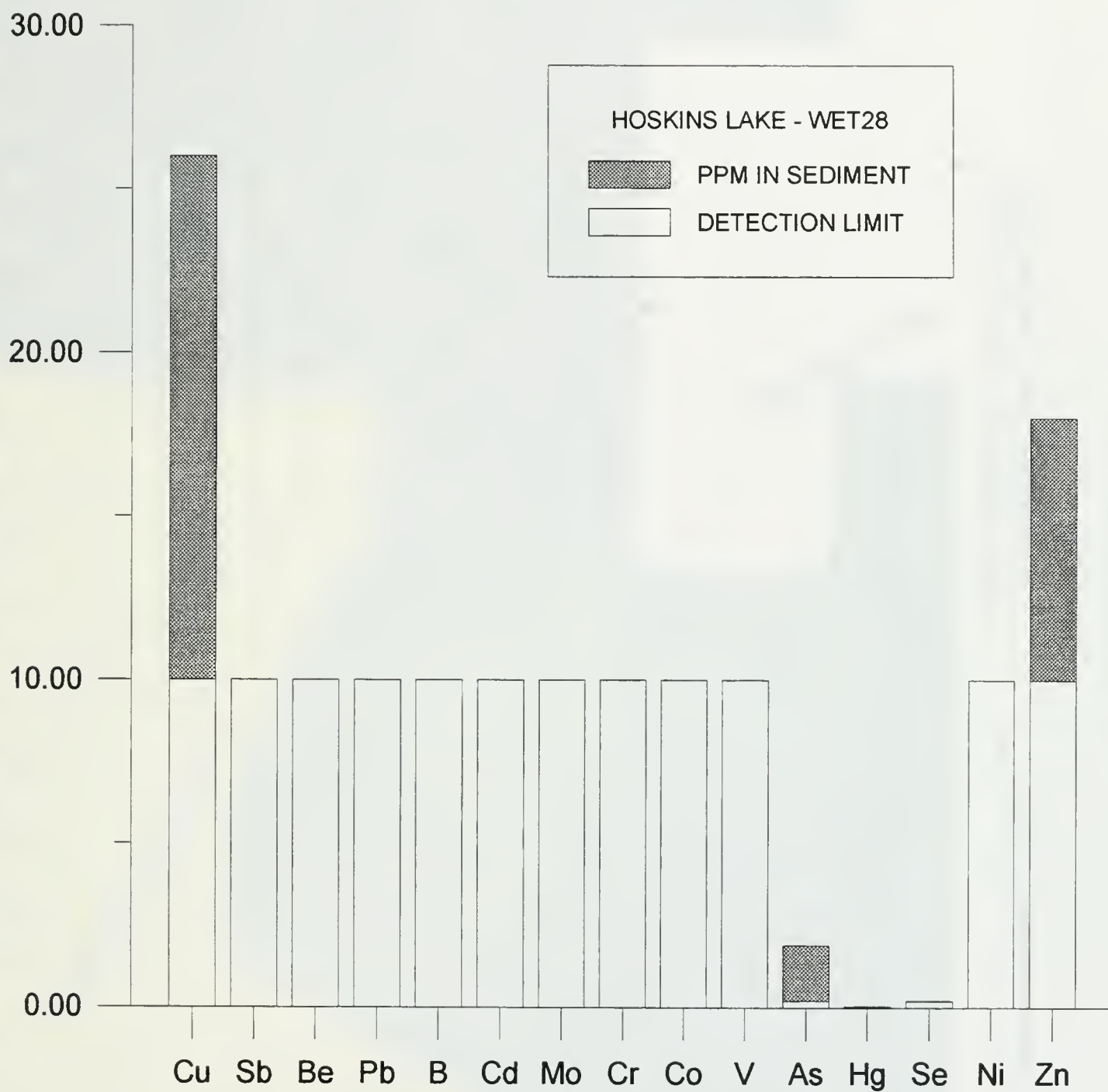
Annual Precipitation in Inches

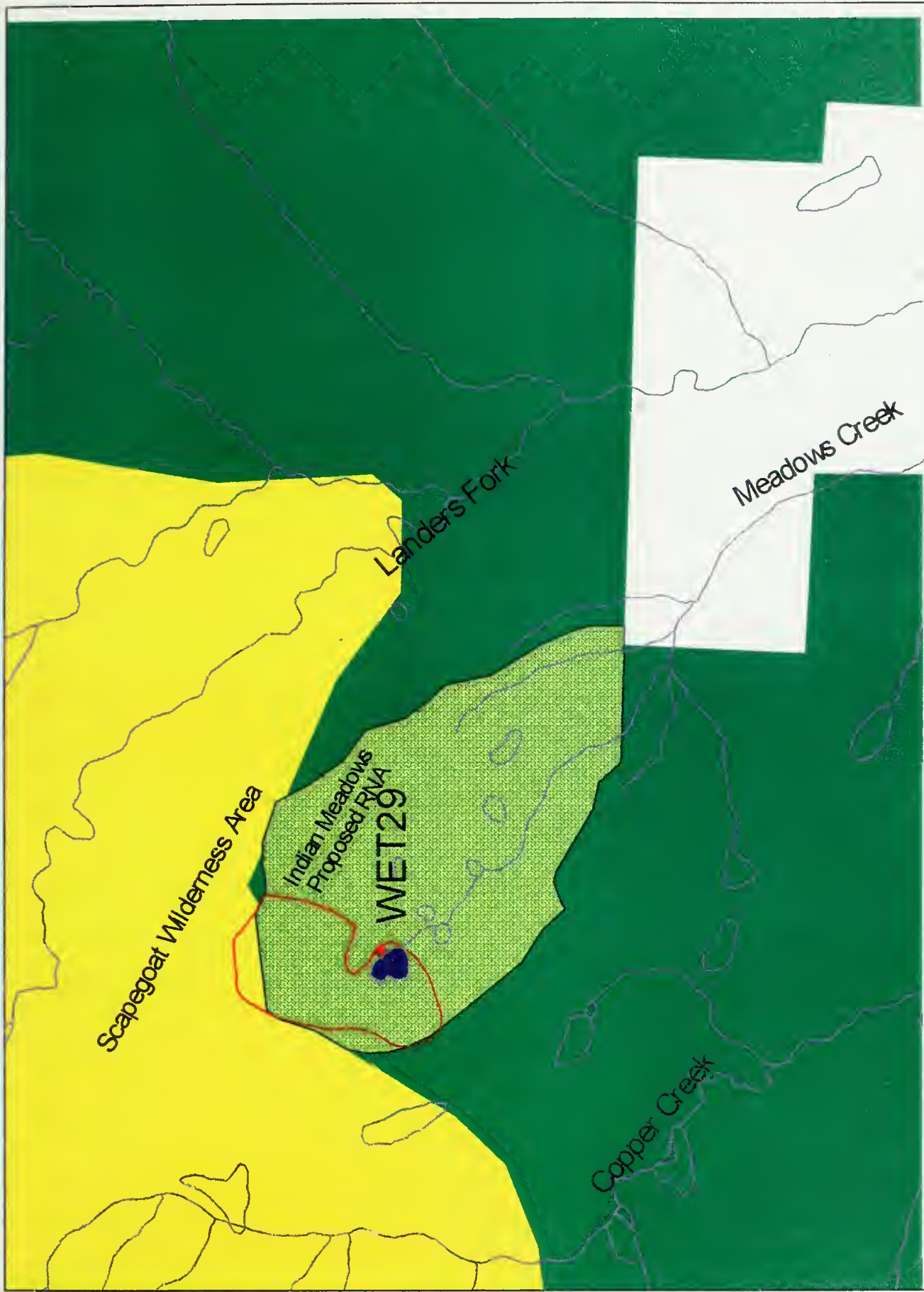




Concentrations in Milligrams per liter







DEQ Wetland Characterization Site
Indian Meadows Proposed RNA

0 0.5 1 1.5 Miles

Wetland: INDIAN MEADOWS PROPOSED RNA

Site Code: WET29

7.5 Minute Quad: SILVER KING MOUNTAIN

Lat: 47 6 25

Long: 112 36 45

Mean Annual Precipitation in Inches: 25.00

Mean Annual Potential Evaporation (Penman) in Inches: 28.00

'Net Precipitation' in Inches: -3.00

Site does not have a mapped surface inlet.

Site has a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 10 acres

Area of contributing drainage basin: 210 acres

Mapped elevation of wetland surface: 6035 ft

Maximum elevation within drainage basin: 6773 ft

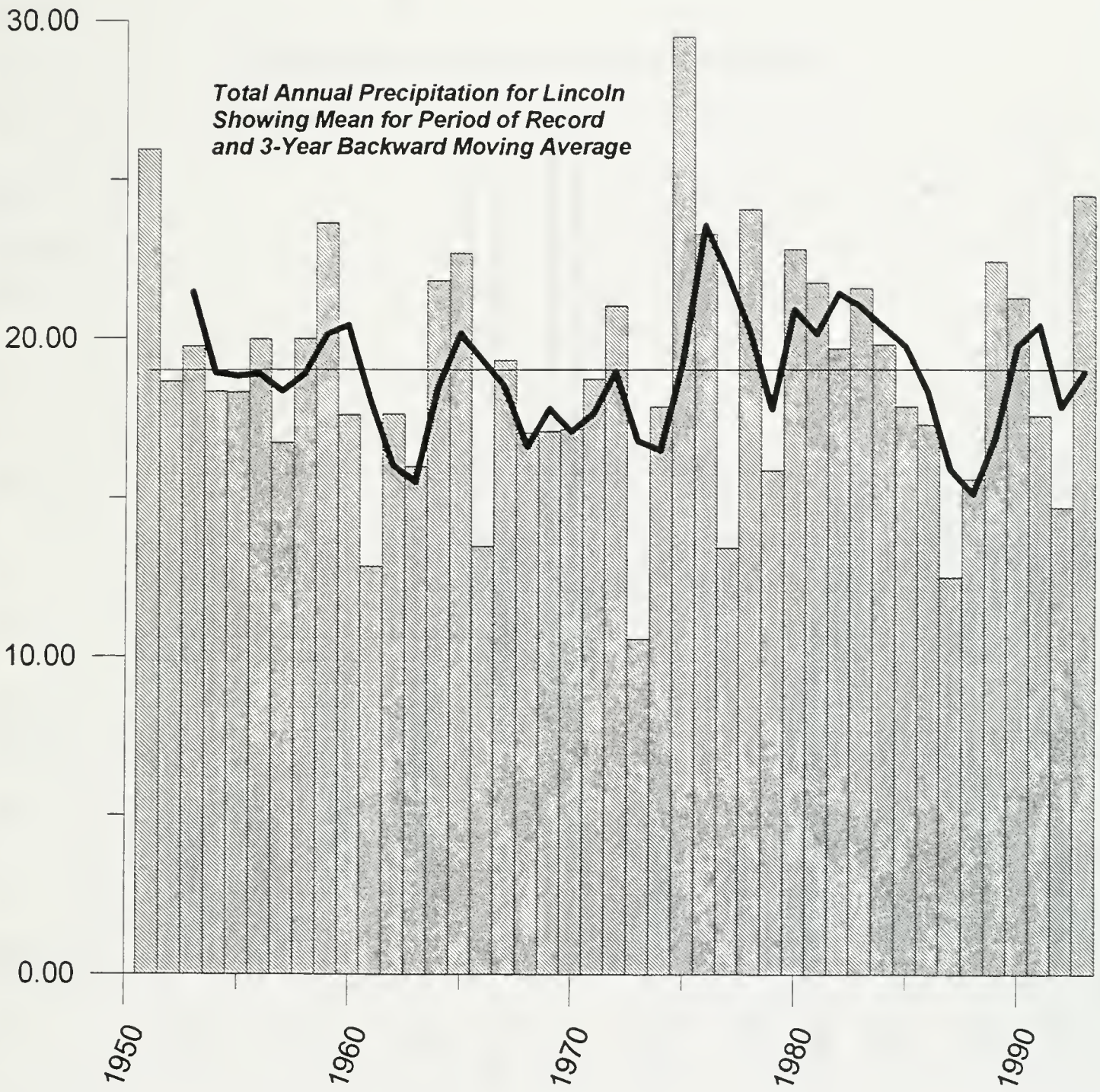
Net relief of contributing basin: 738 ft

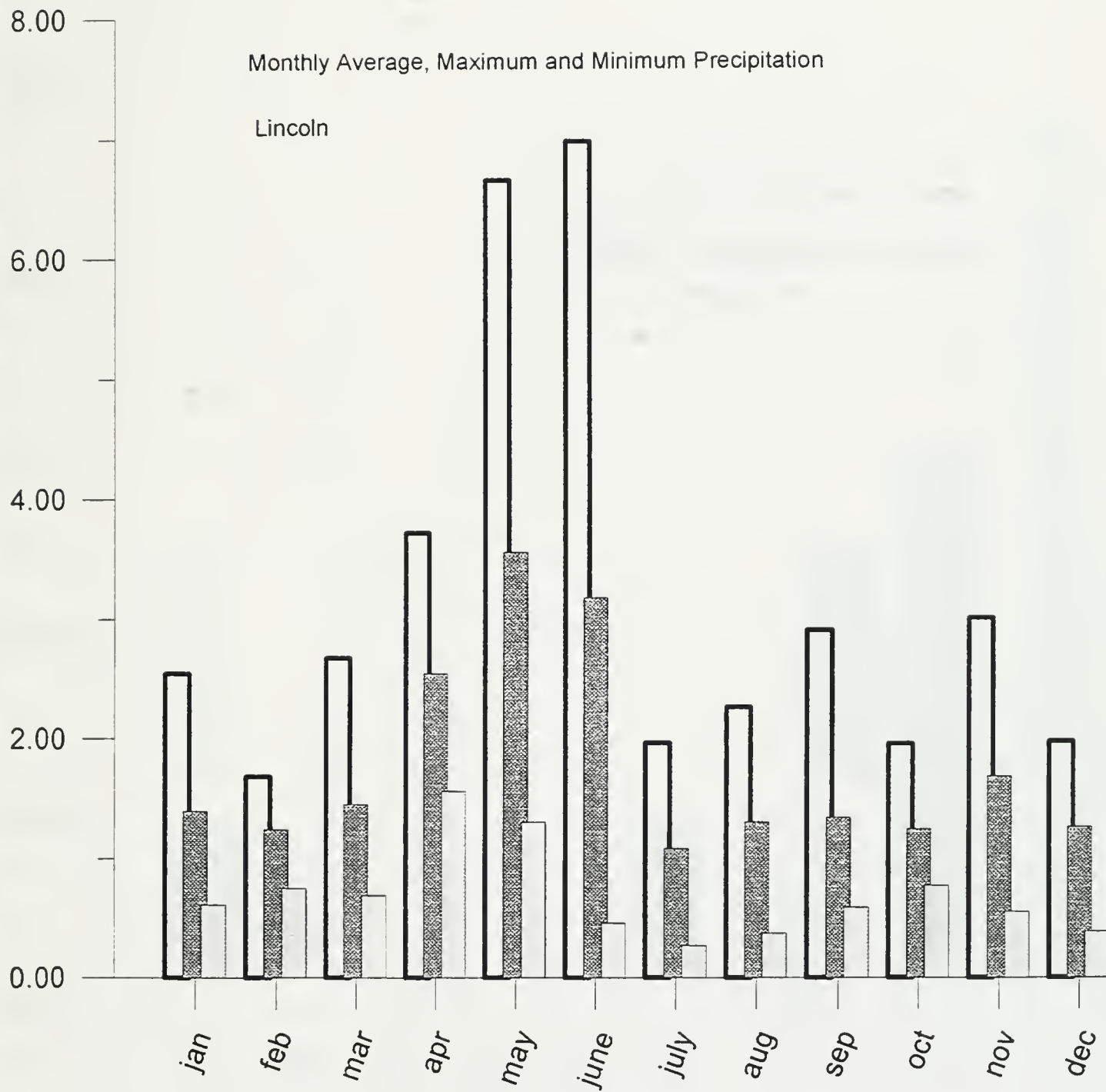
COE Hydrogeomorphic class: DEPRESSIONAL

Primary surficial geologic unit 112DRFT

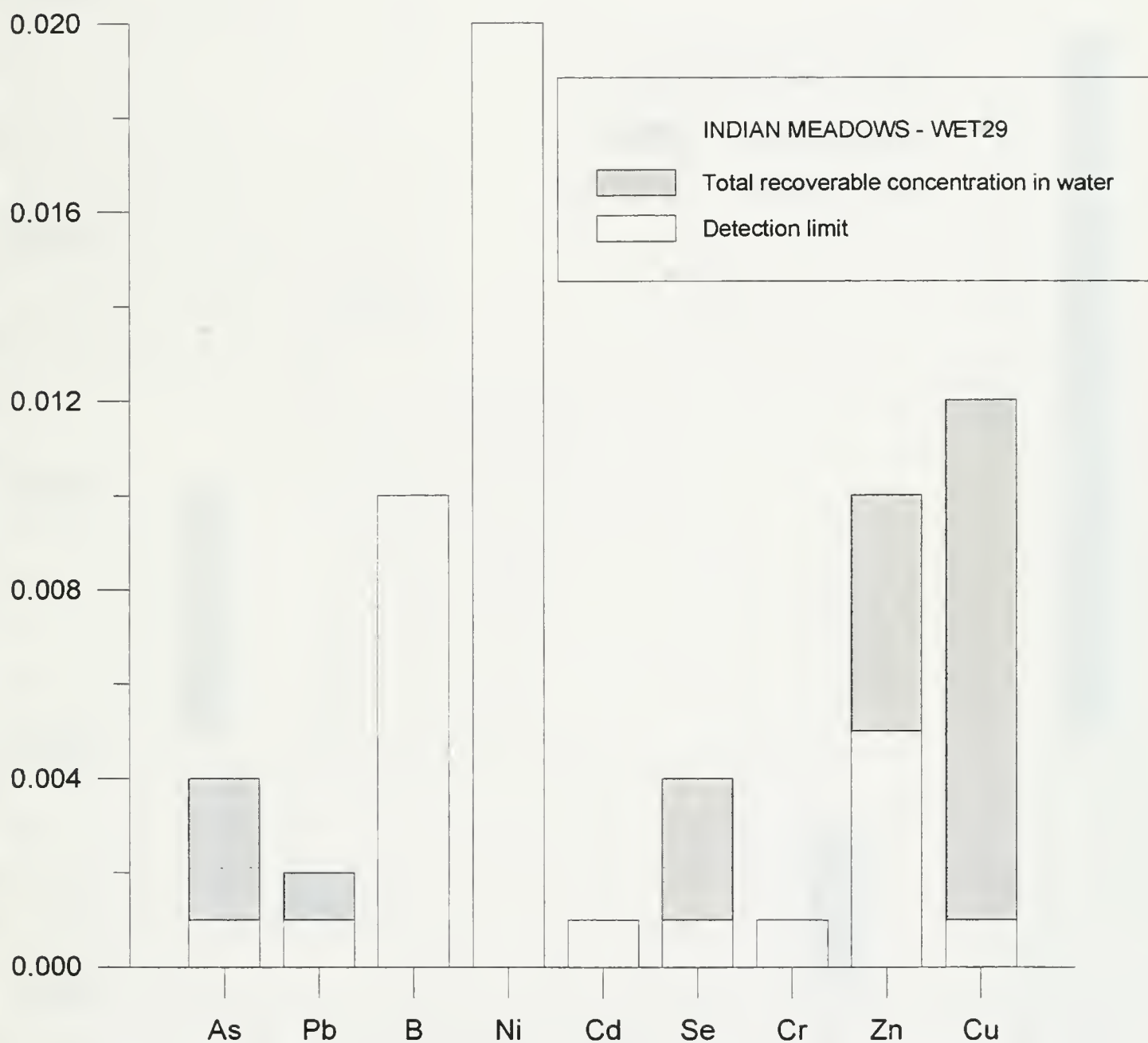
Primary bedrock geologic unit 120VLCC

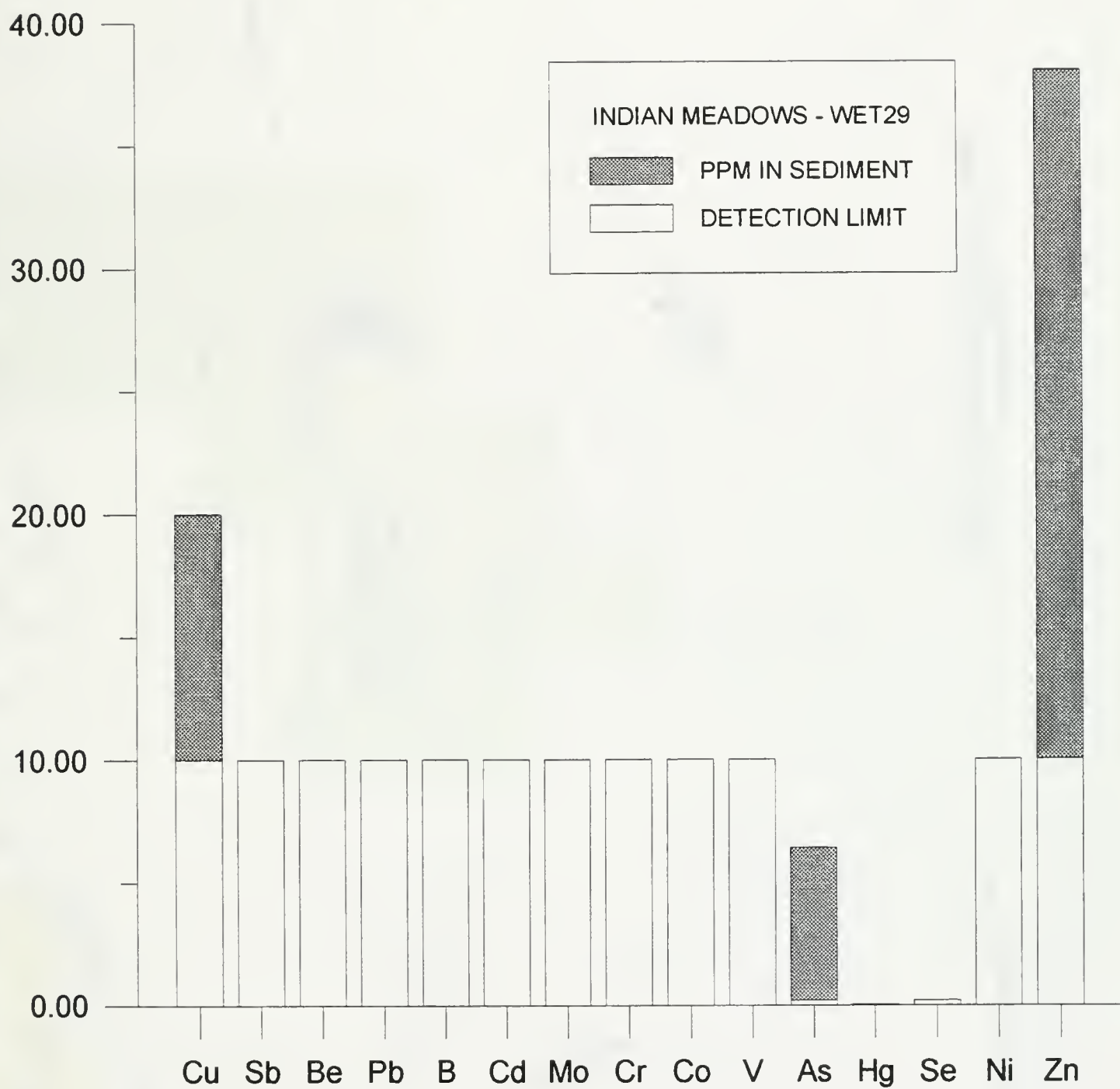
Annual Precipitation in Inches

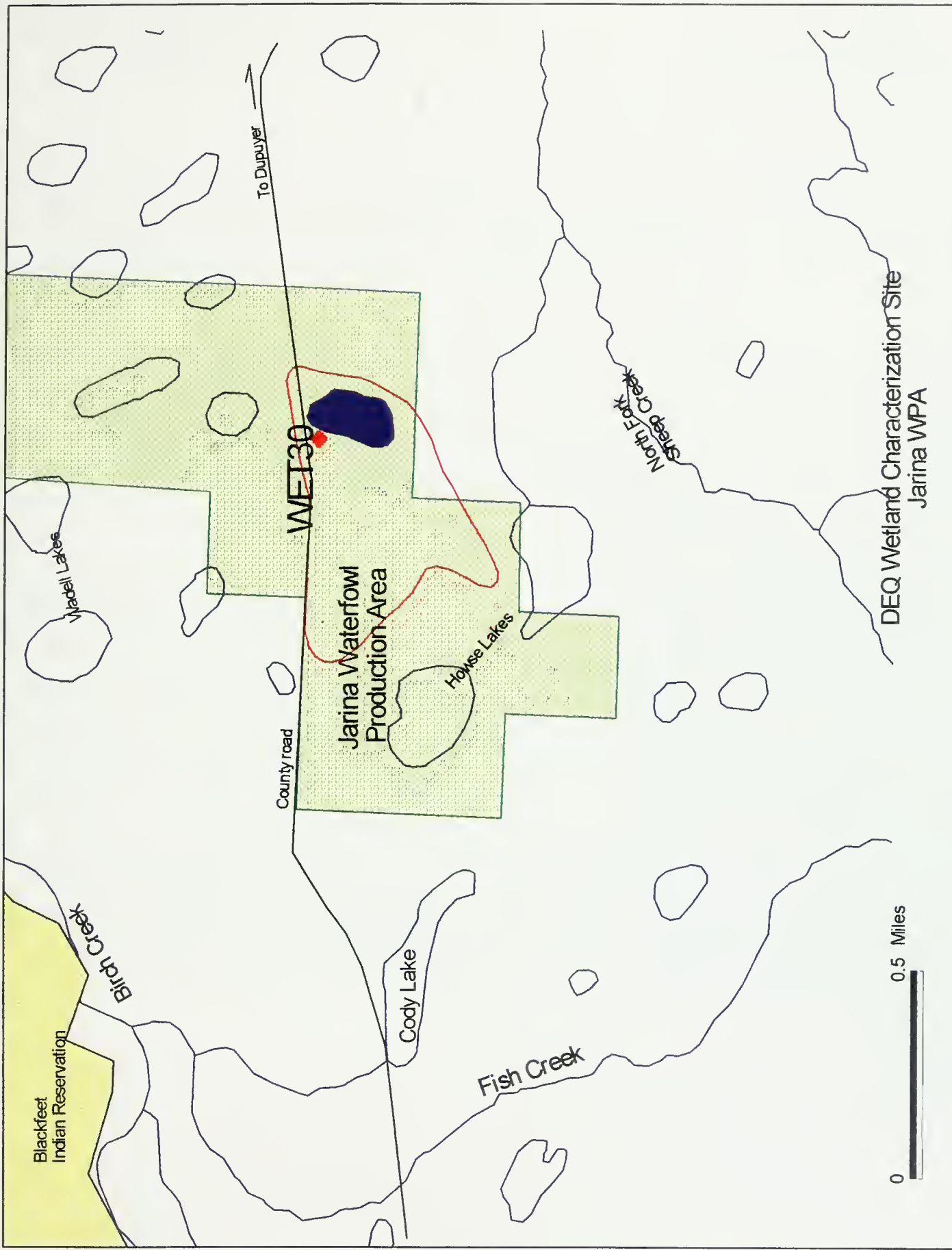




Concentrations in Milligrams per liter







Blackfeet
Indian Reservation

Bird Creek

Madell Lakes

To Dupuyer

County road

WEI30

Jarina Waterfowl
Production Area

Howse Lakes

Cody Lake

Fish Creek

North Fork
Sheep Creek

DEQ Wetland Characterization Site
Jarina WPA

0 0.5 Miles

Wetland: JARINA WPA

Site Code: WET30

7.5 Minute Quad: FISH LAKE

Lat: 48 10 35

Long: 112 47 25

Mean Annual Precipitation in Inches:	25.00
Mean Annual Potential Evaporation (Penman) in Inches:	34.00
'Net Precipitation' in Inches:	-9.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

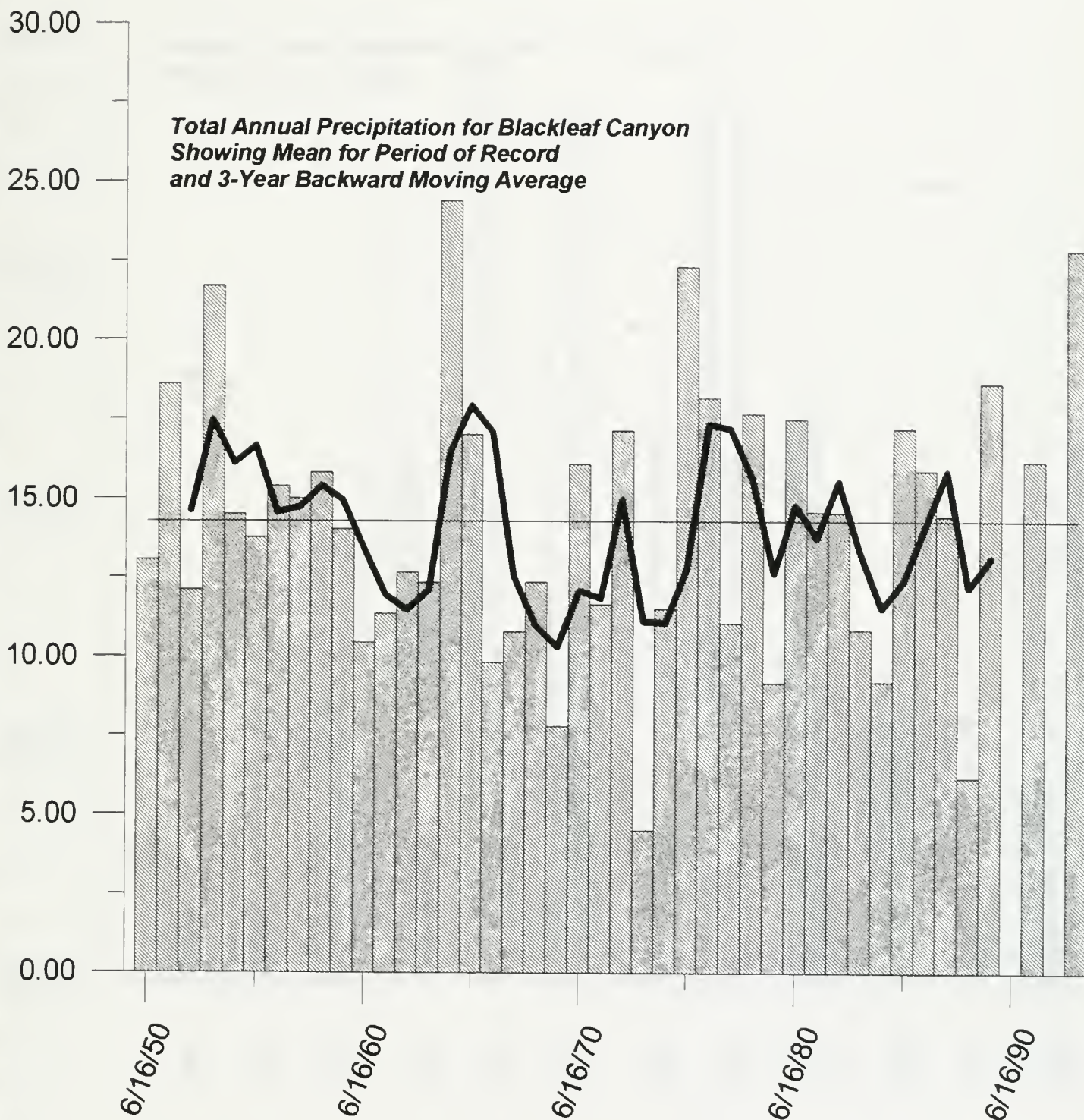
Site is not known to be artificially impounded.

Site does not have known significant water imports.

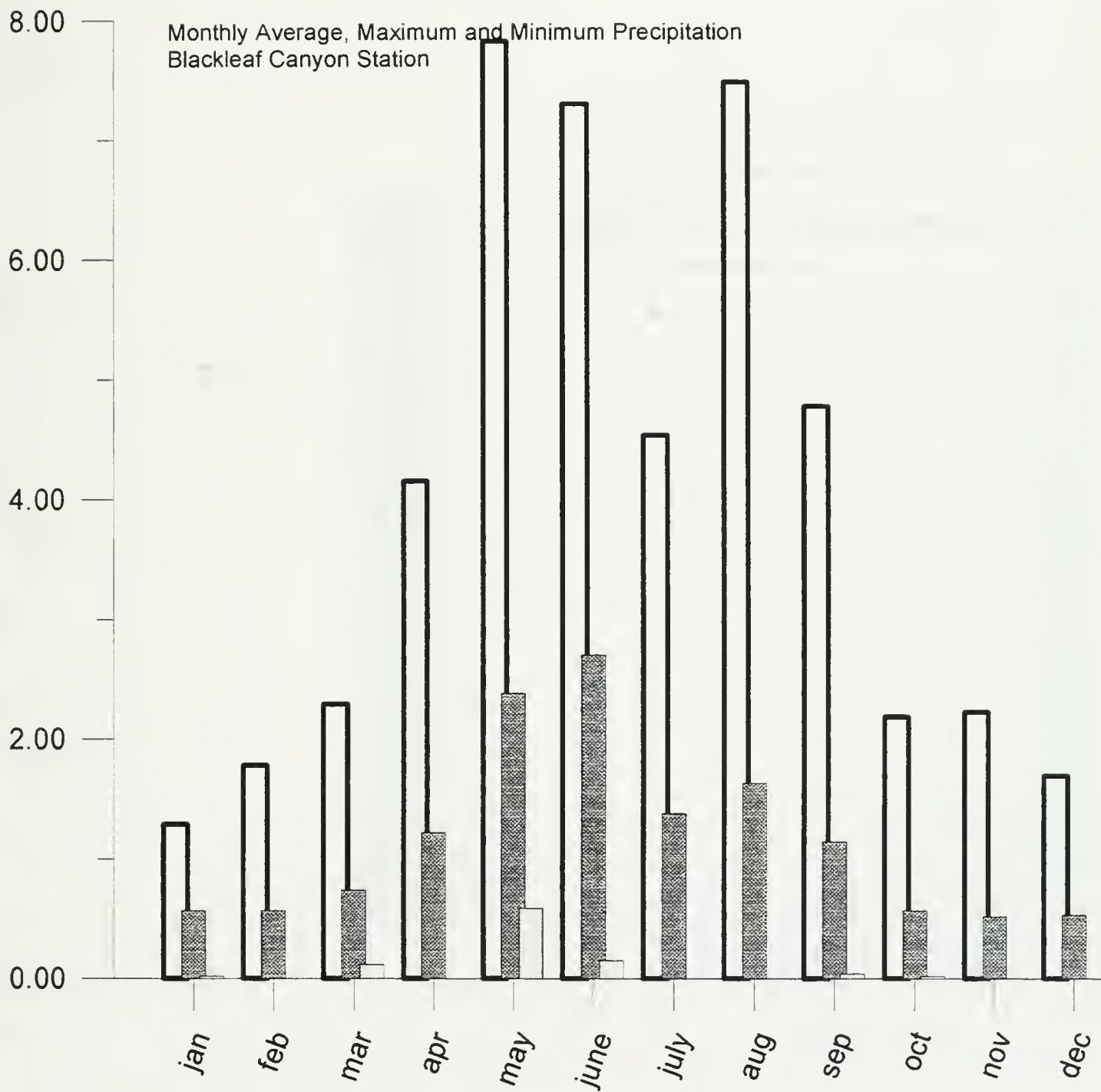
Mapped area of wetland:	12 acres
Area of contributing drainage basin:	130 acres
Mapped elevation of wetland surface:	4675 ft
Maximum elevation within drainage basin:	4765 ft
Net relief of contributing basin:	90 ft

COE Hydrogeomorphic class:	FRINGE
Primary surficial geologic unit	112TILL
Primary bedrock geologic unit	210CRCS

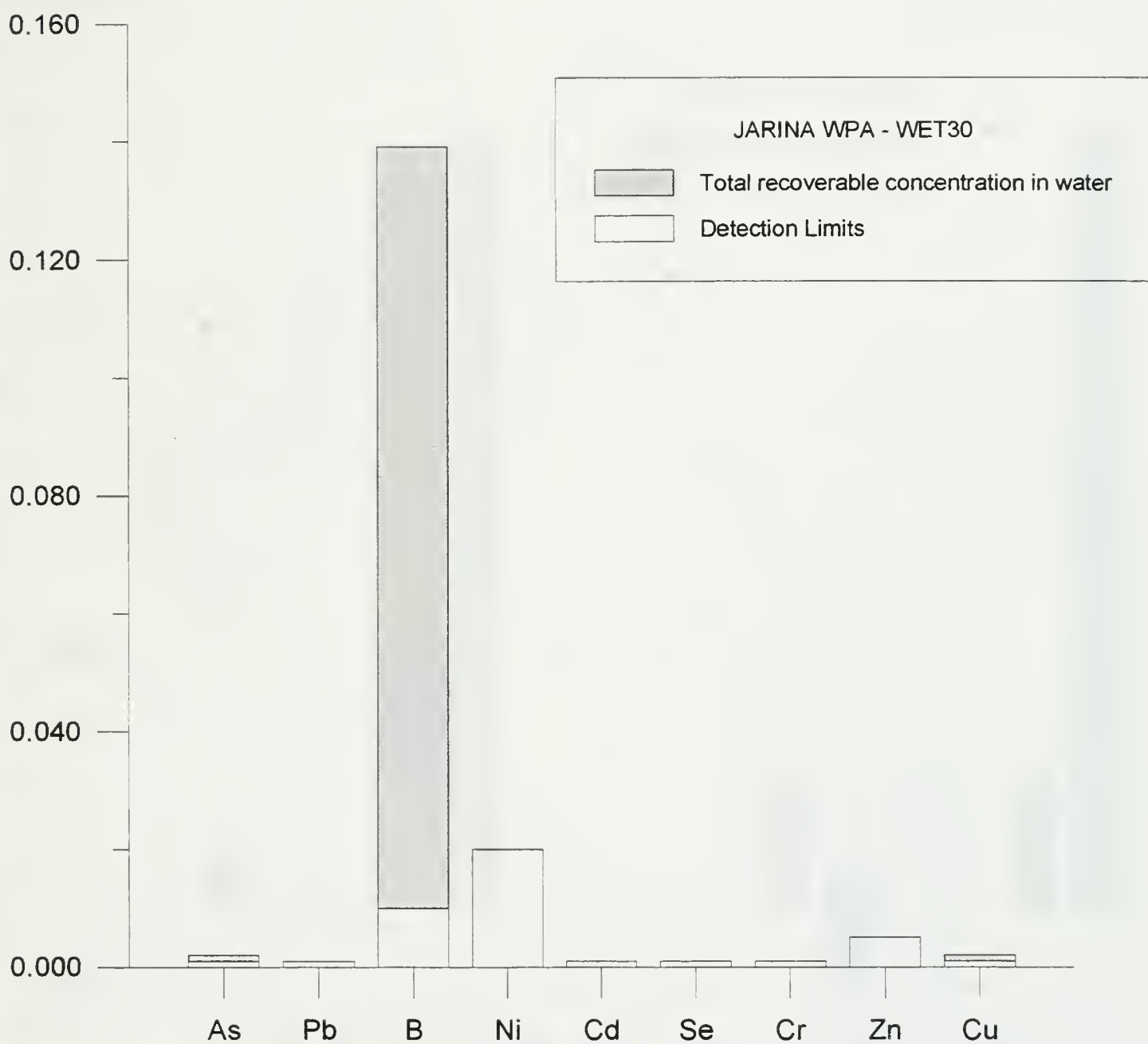
Annual Precipitation in Inches



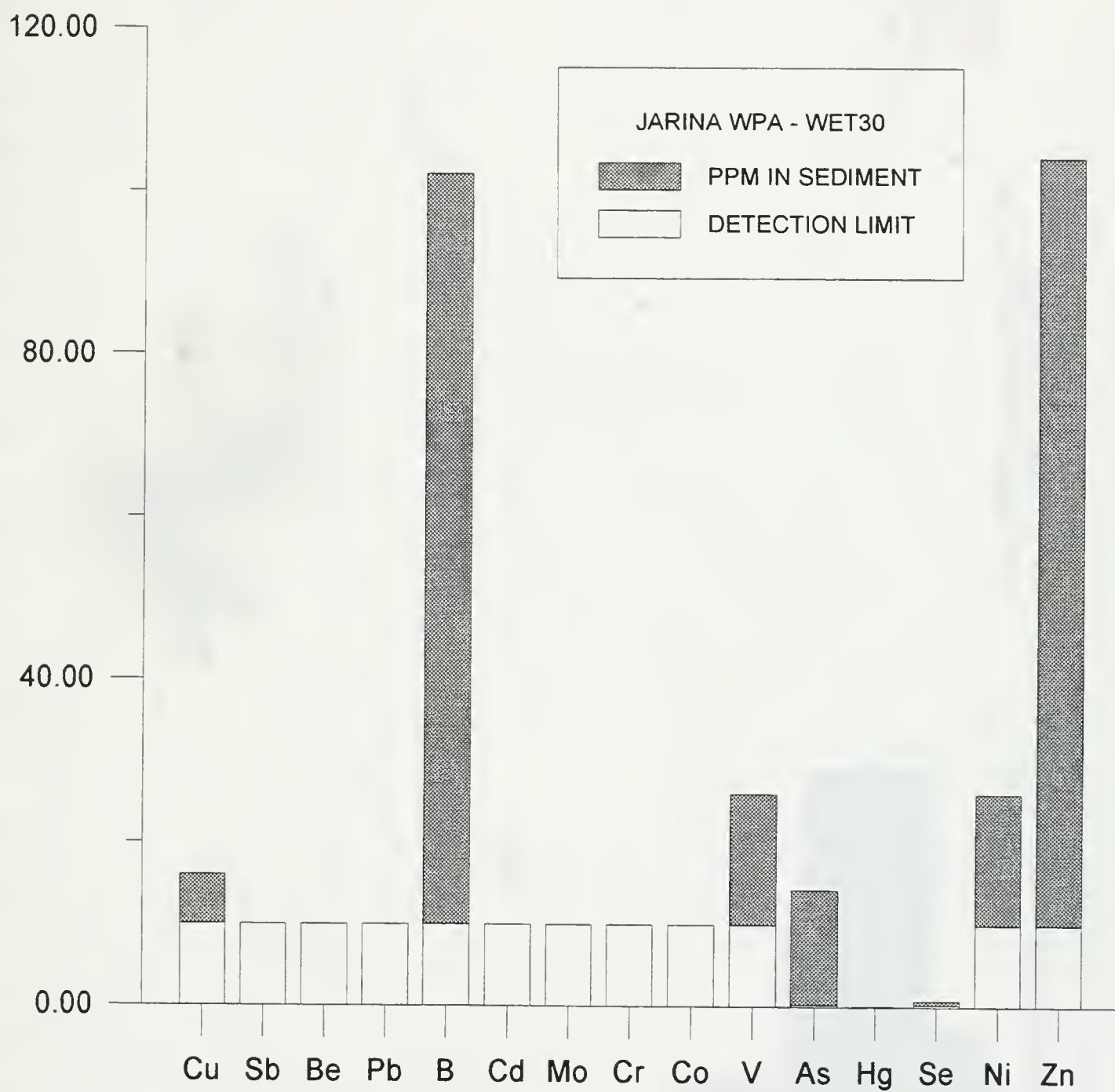
Inches Precipitation

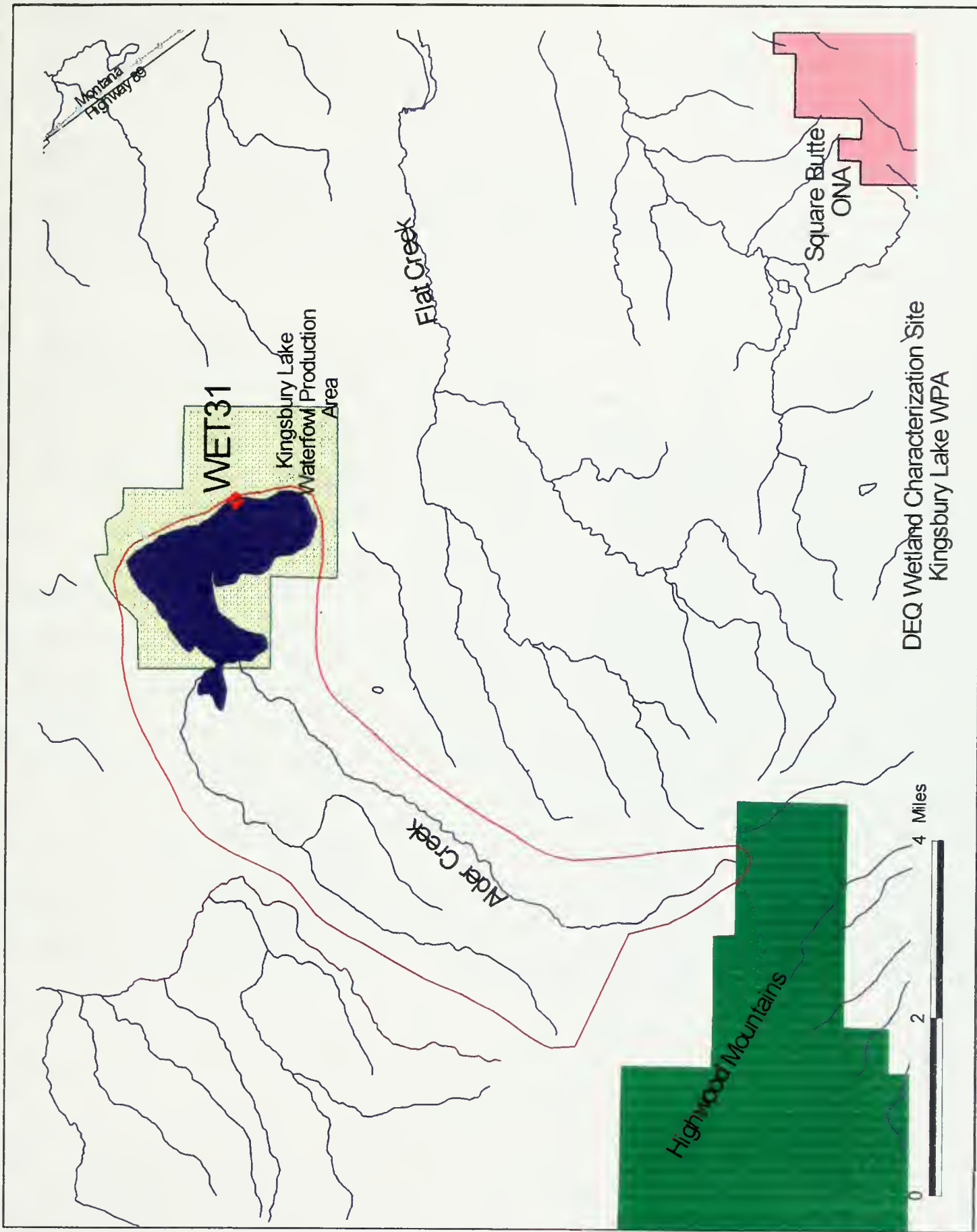


Concentrations in Milligrams per liter



HNO3 - Extractable Sediment Concentrations in PPM





Wetland: KINGSBURY WPA

Site Code: WET31

7.5 Minute Quad: GERALDINE

Lat: 47 34 0

Long: 110 20 45

Mean Annual Precipitation in Inches: 17.00

Mean Annual Potential Evaporation (Penman) in Inches: 41.00

'Net Precipitation' in Inches: -24.00

Site has a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 1375 acres

Area of contributing drainage basin: 10420 acres

Mapped elevation of wetland surface: 3182 ft

Maximum elevation within drainage basin: 6034 ft

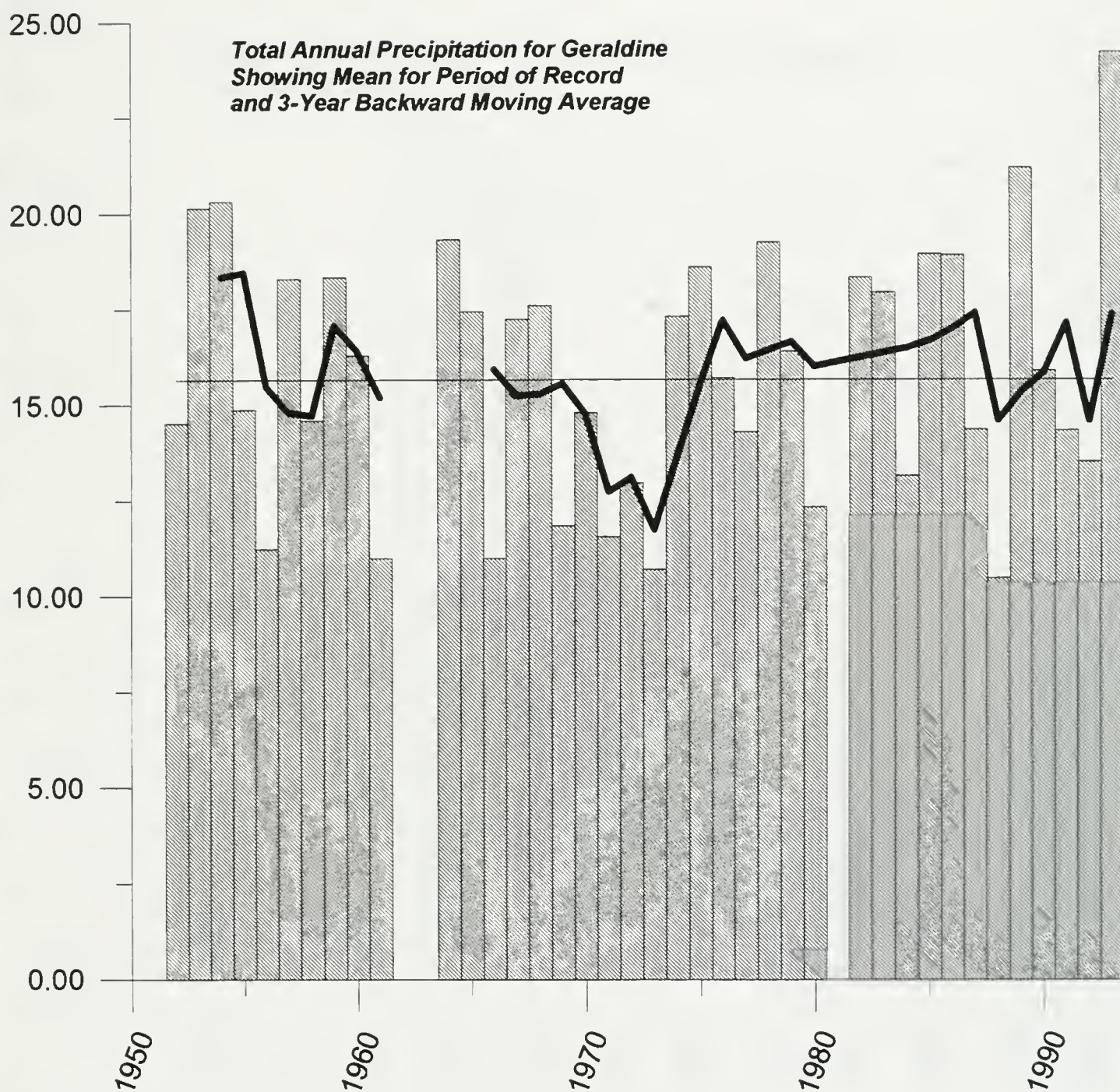
Net relief of contributing basin: 2852 ft

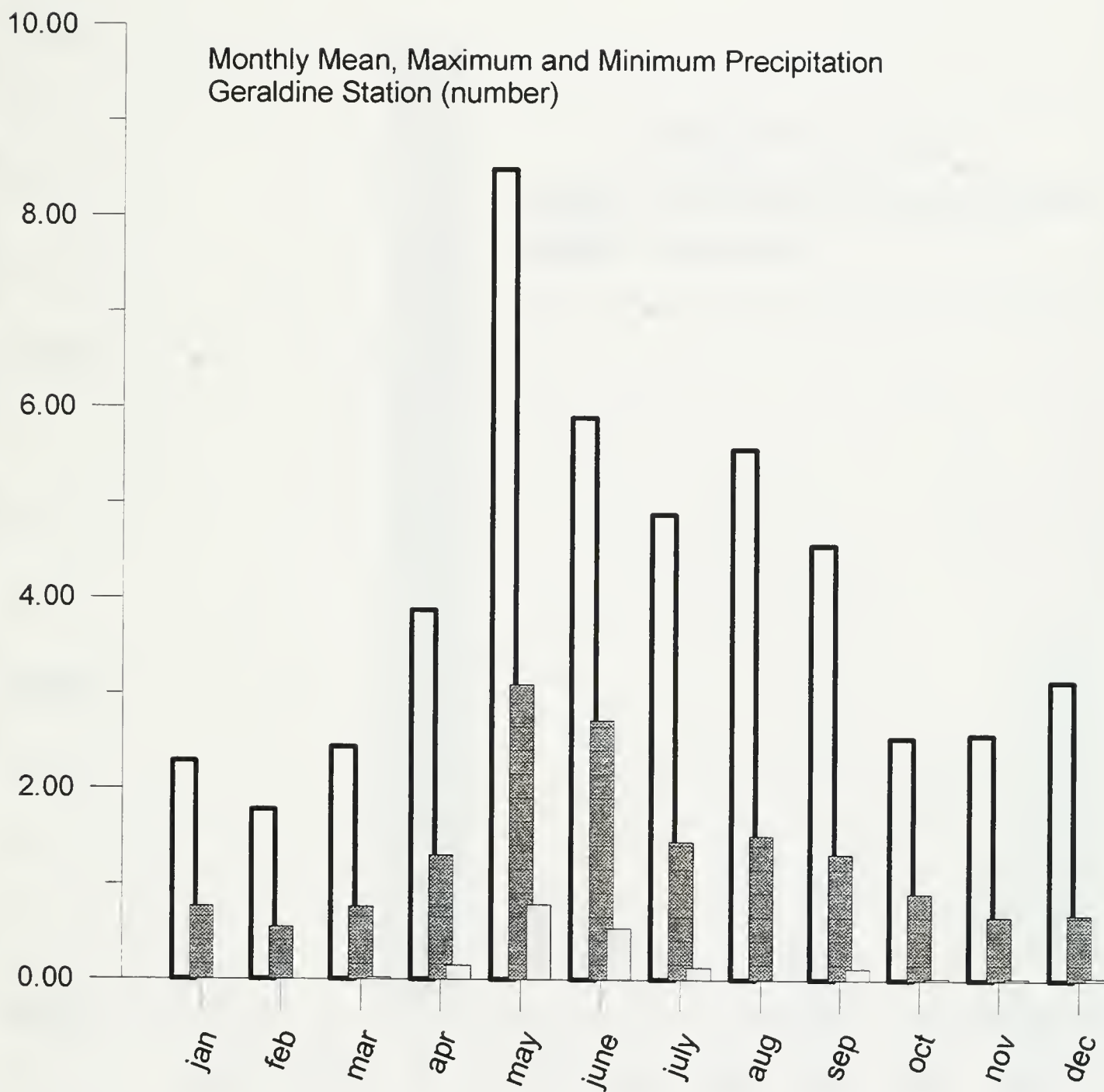
COE Hydrogeomorphic class: FRINGE

Primary surficial geologic unit 110"LAC"

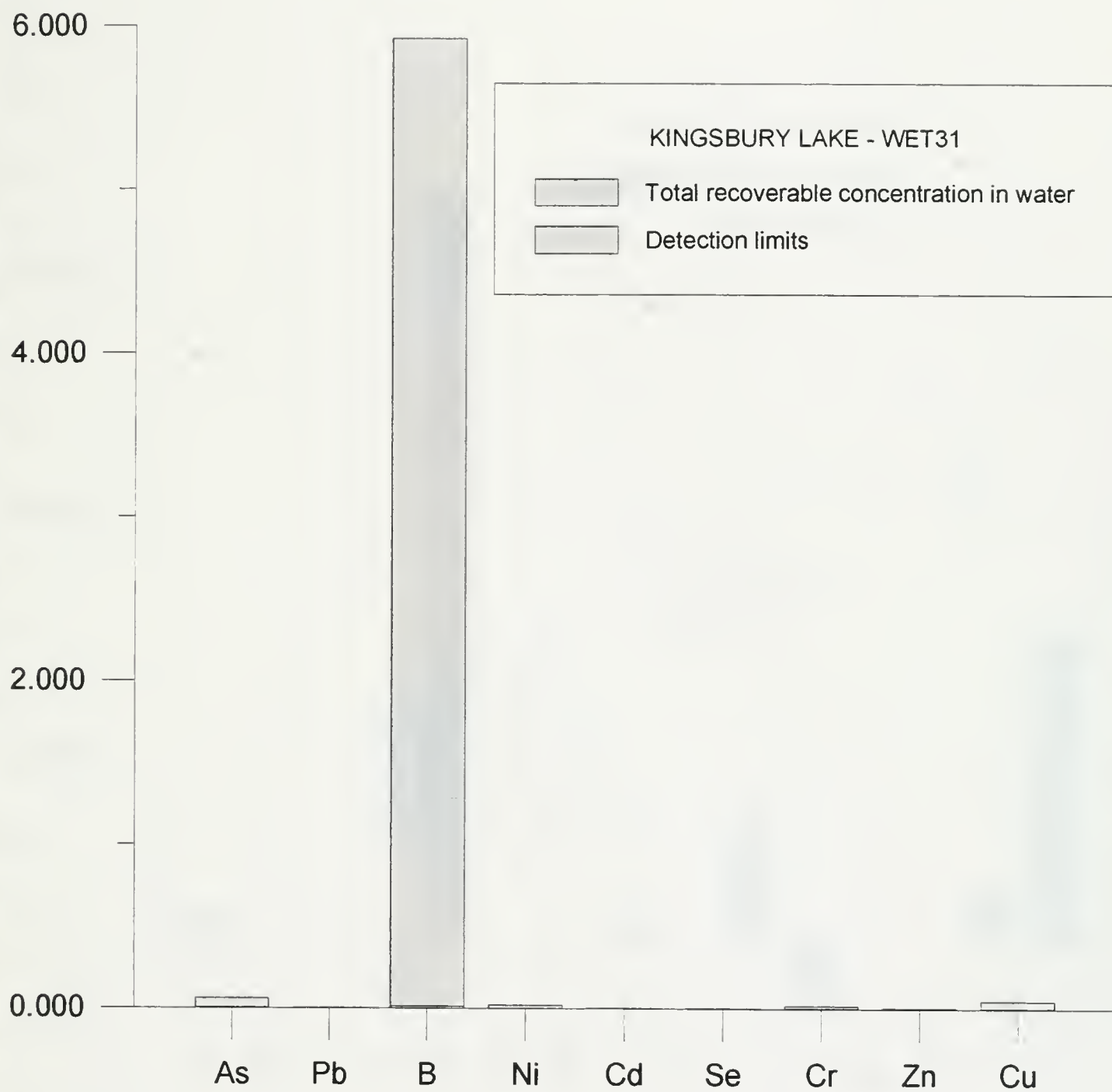
Primary bedrock geologic unit 211CLRD

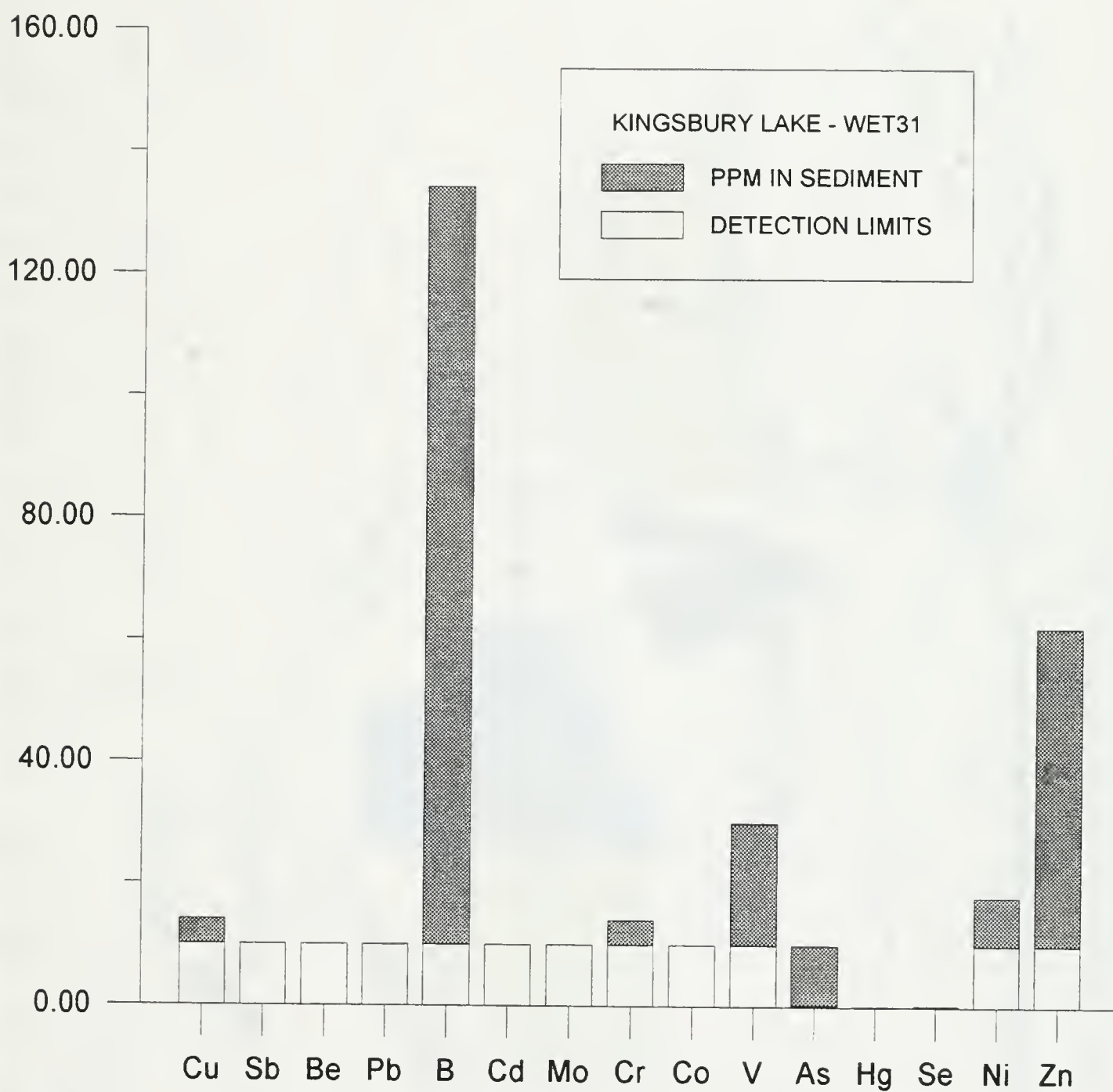
Annual Precipitation in Inches

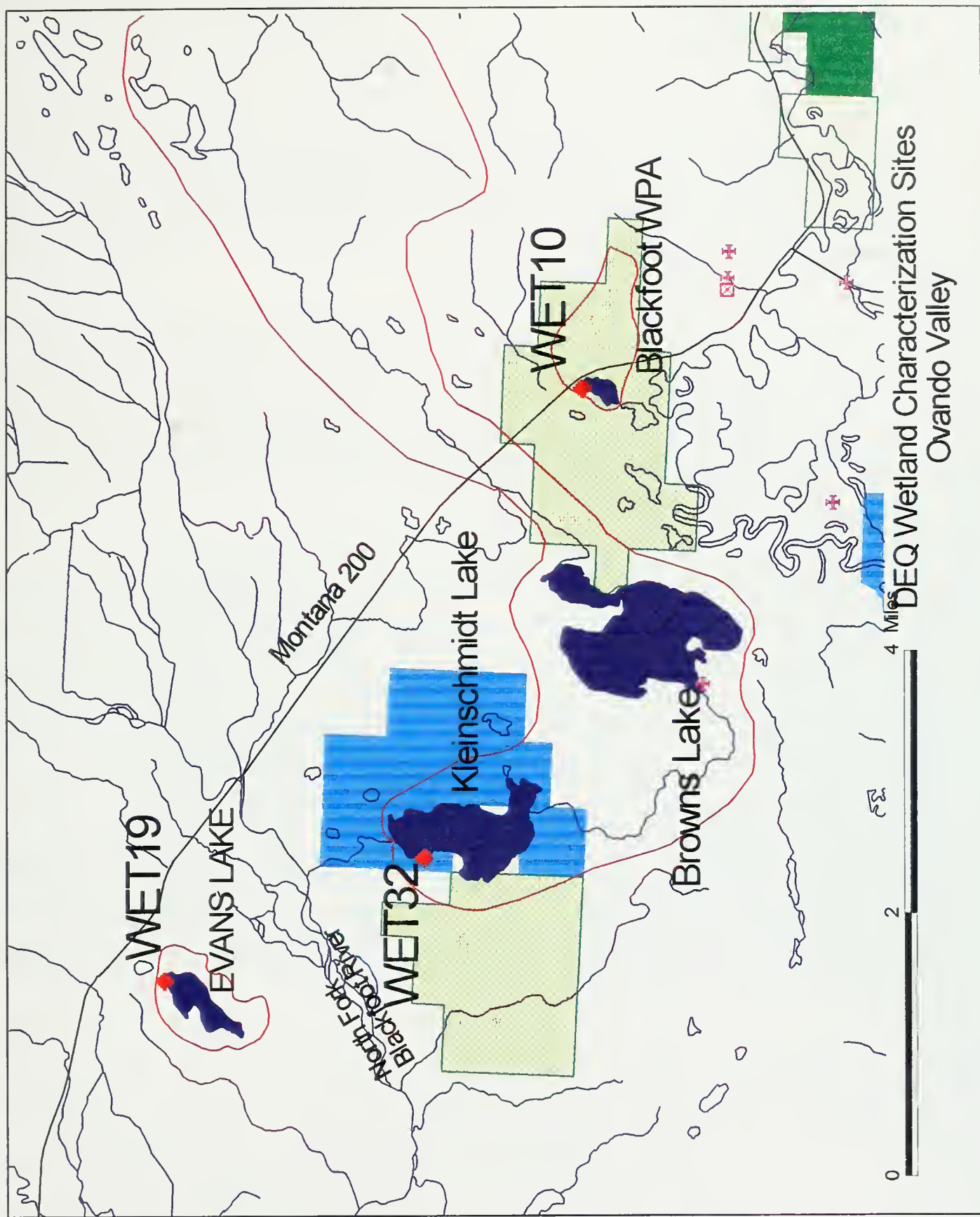




Concentrations in Milligrams per liter







DEQ Wetland Characterization Sites
Ovando Valley

Wetland: KLEINSCHMIDT LAKE WPA

Site Code: WET32

7.5 Minute Quad: BROWNS LAKE

Lat: 46 58 45

Long: 113 2 45

Mean Annual Precipitation in Inches: 15.00

Mean Annual Potential Evaporation (Penman) in Inches: 33.00

'Net Precipitation' in Inches: -18.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 285 acres

Area of contributing drainage basin: 7350 acres

Mapped elevation of wetland surface: 4182 ft

Maximum elevation within drainage basin: 7253 ft

Net relief of contributing basin: 3071 ft

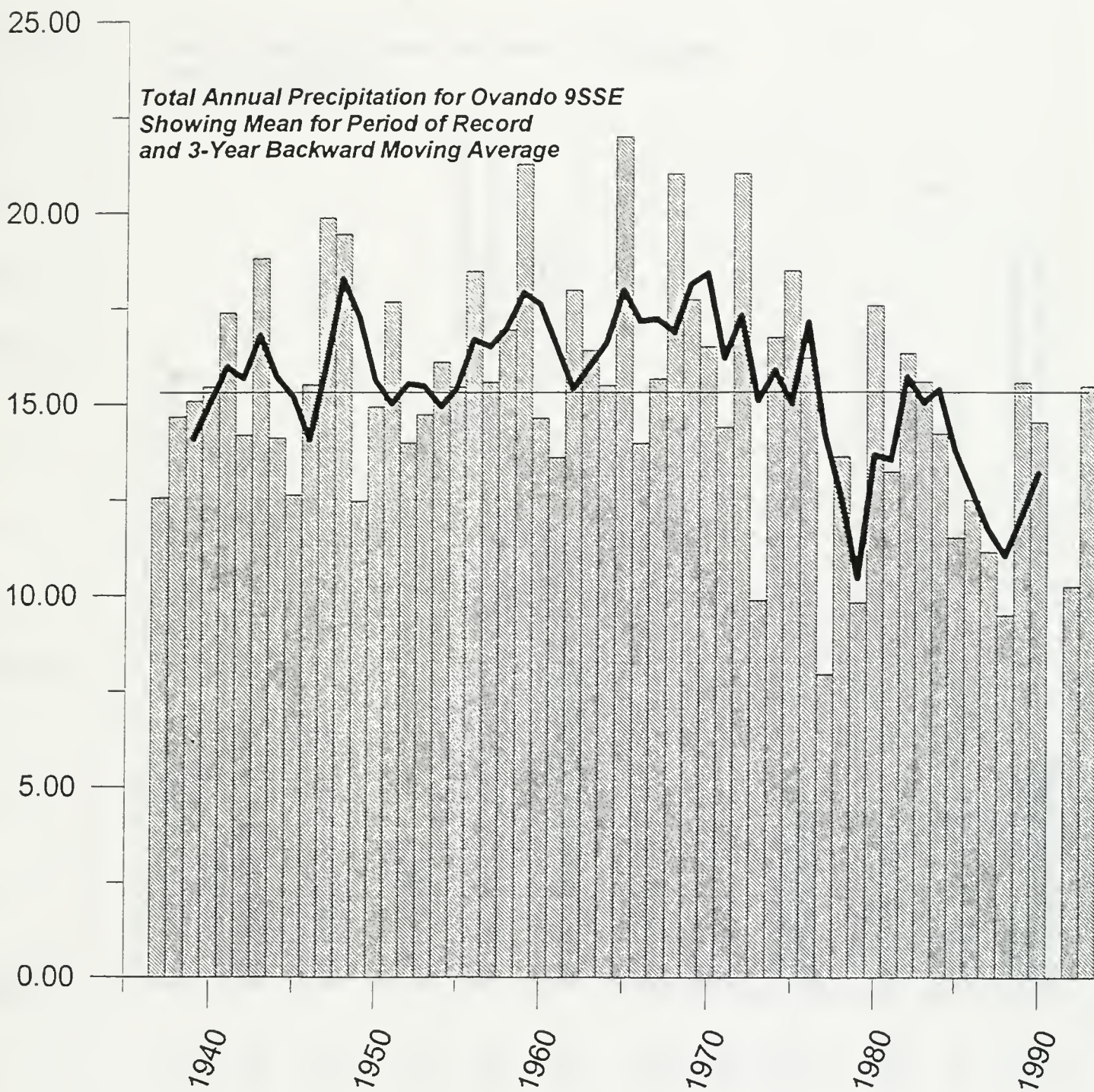
COE Hydrogeomorphic class: FRINGE

Primary surficial geologic unit 112TILL

Primary bedrock geologic unit 120SDMS

*Total Annual Precipitation for Ovando 9SSE
Showing Mean for Period of Record
and 3-Year Backward Moving Average*

Annual Precipitation in Inches



Inches Precipitation

6.00

Monthly Average, Maximum and Minimum Precipitation
Ovando 9 SSE Station

4.00

2.00

0.00

jan

feb

mar

apr

may

june

july

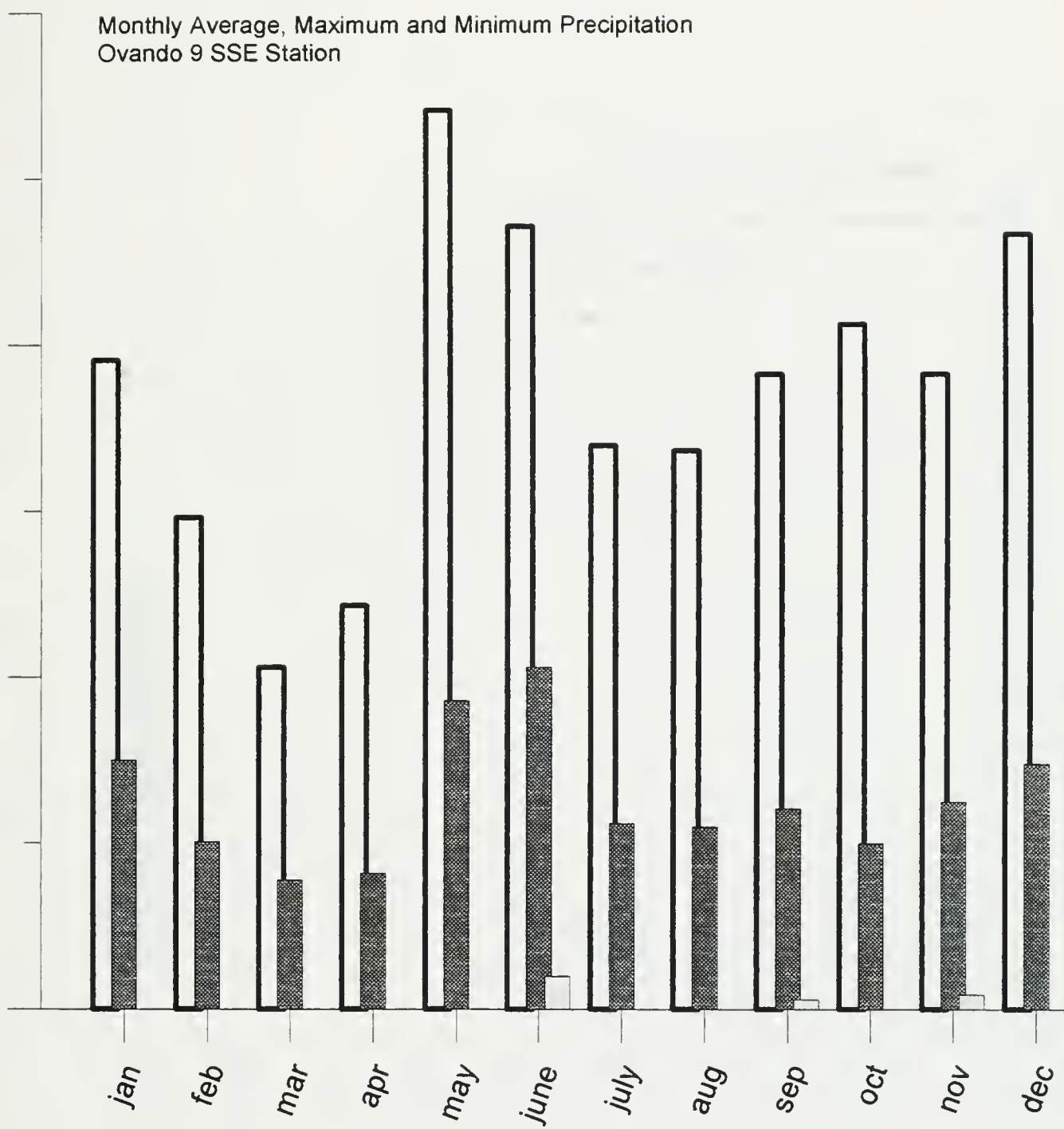
aug

sep

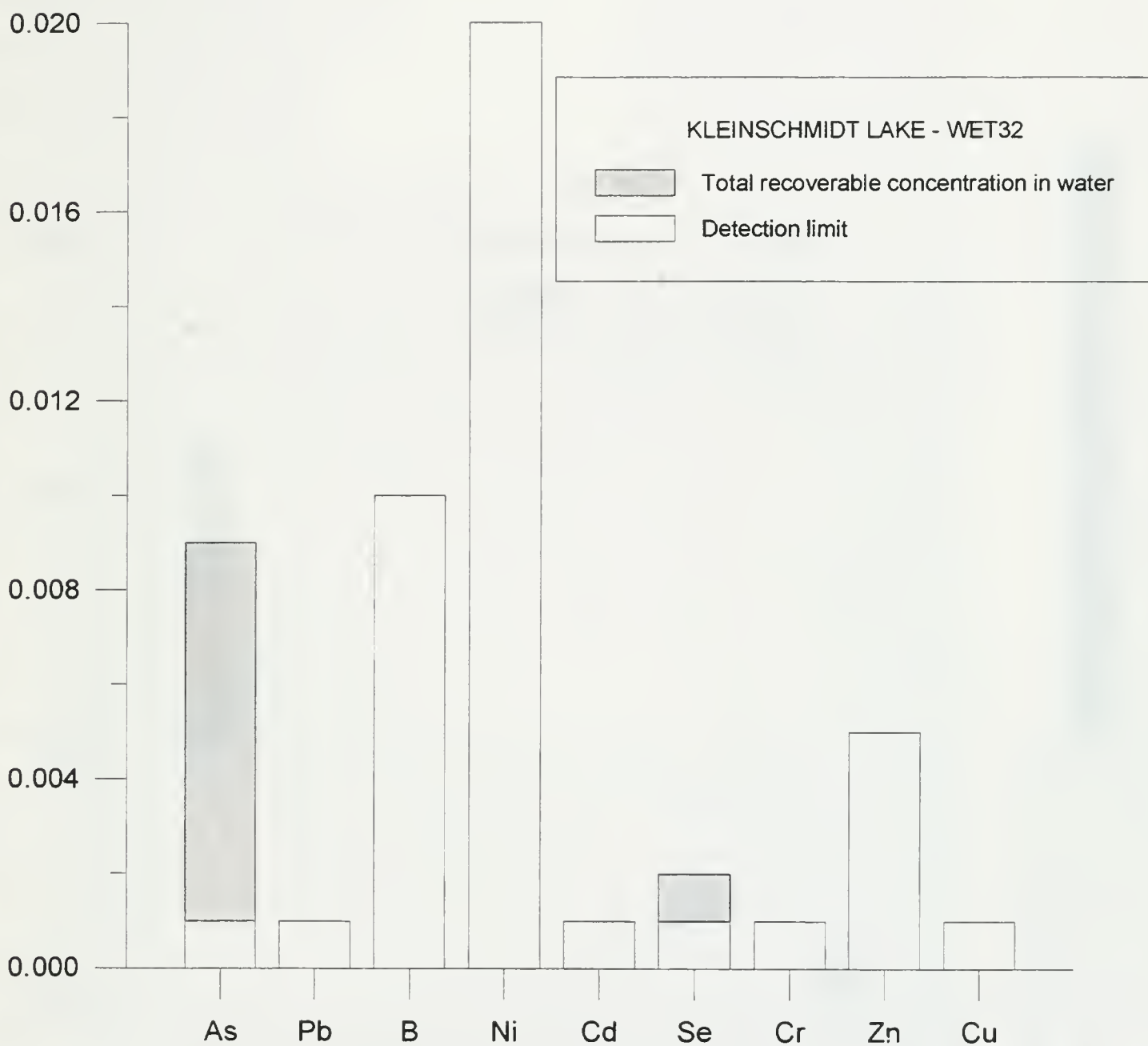
oct

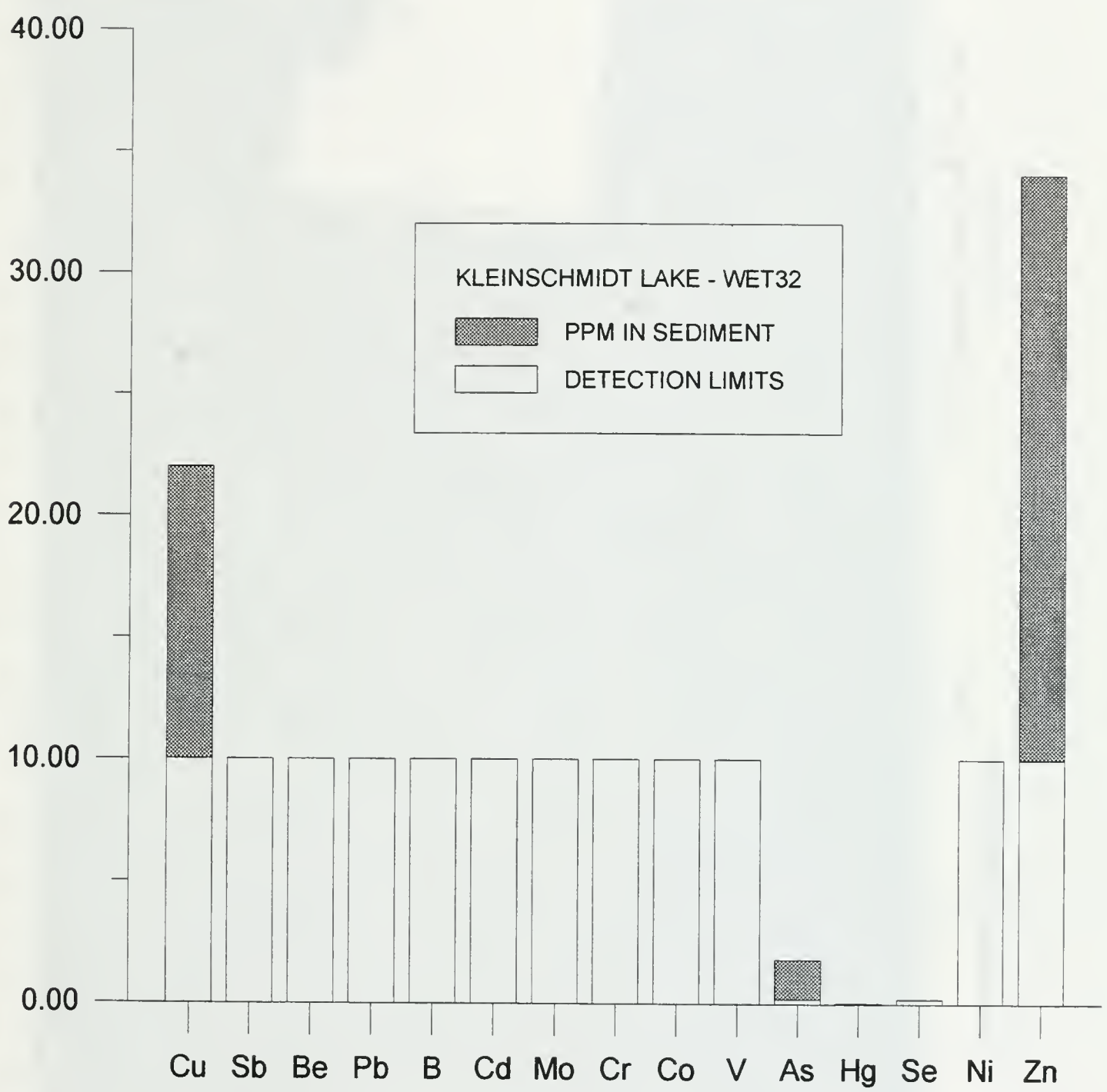
nov

dec



Concentrations in Milligrams per liter







DEQ Wetland Characterization Site
LaFoe Lake



Wetland: LAFOE LAKE

Site Code: WET33

7.5 Minute Quad: TURNER MOUNTAIN

Lat: 48 37 10

Long: 115 41 5

Mean Annual Precipitation in Inches: 35.00

Mean Annual Potential Evaporation (Penman) in Inches: 27.00

'Net Precipitation' in Inches: 8.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 11 acres

Area of contributing drainage basin: 1230 acres

Mapped elevation of wetland surface: 3800 ft

Maximum elevation within drainage basin: 5952 ft

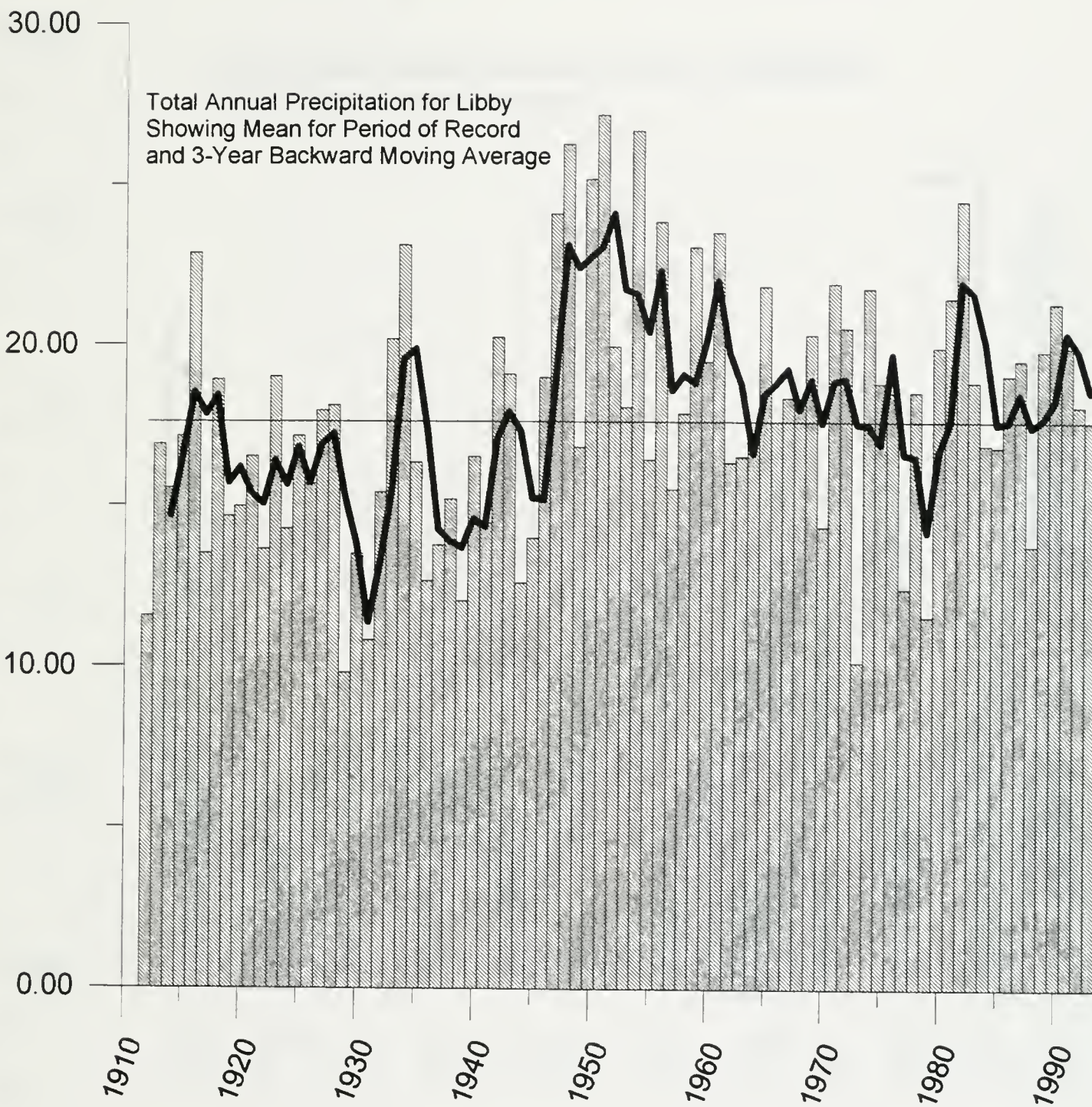
Net relief of contributing basin: 2152 ft

COE Hydrogeomorphic class: DEPRESSIONAL

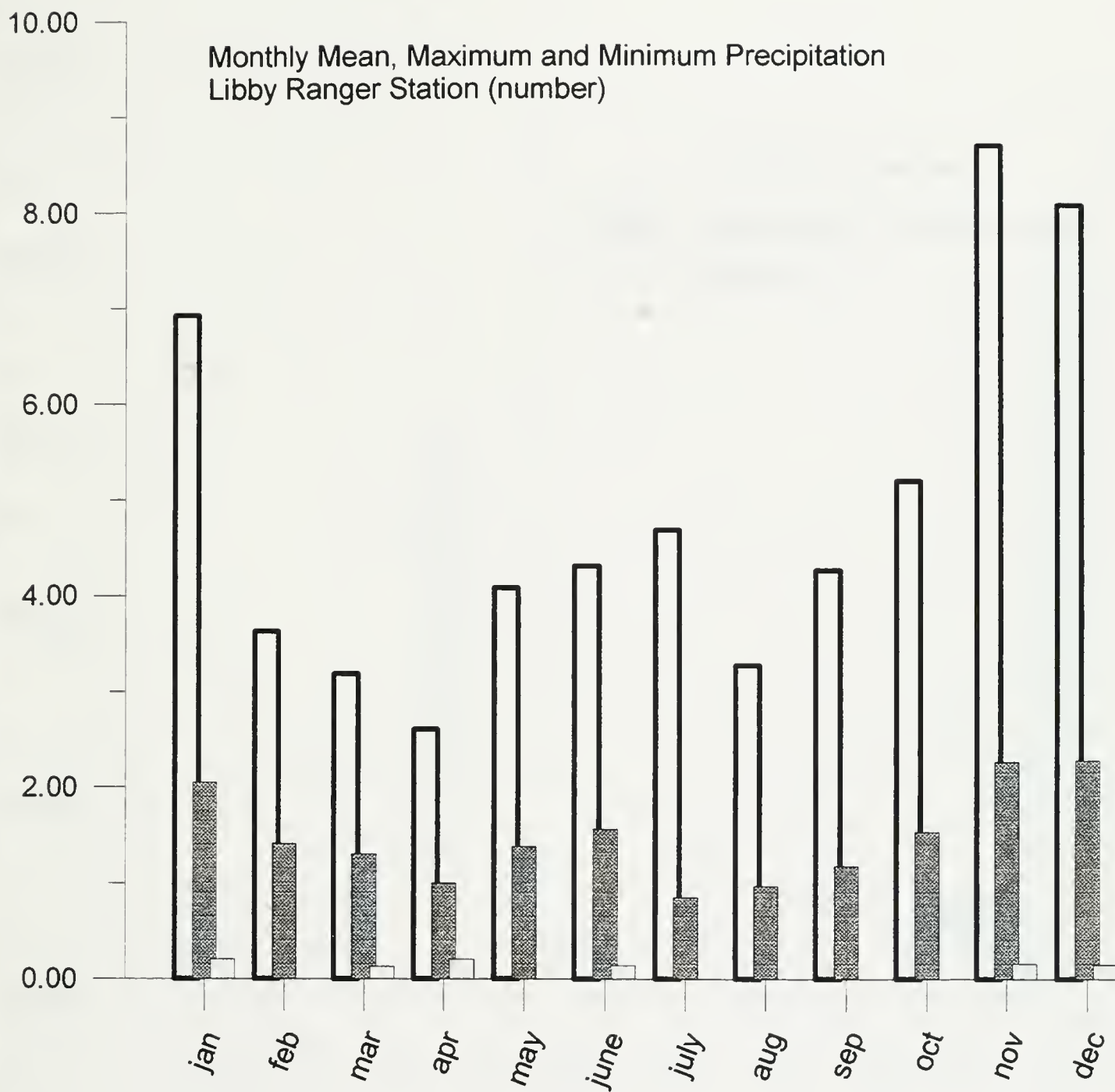
Primary surficial geologic unit 110ALVM

Primary bedrock geologic unit 400WLLC

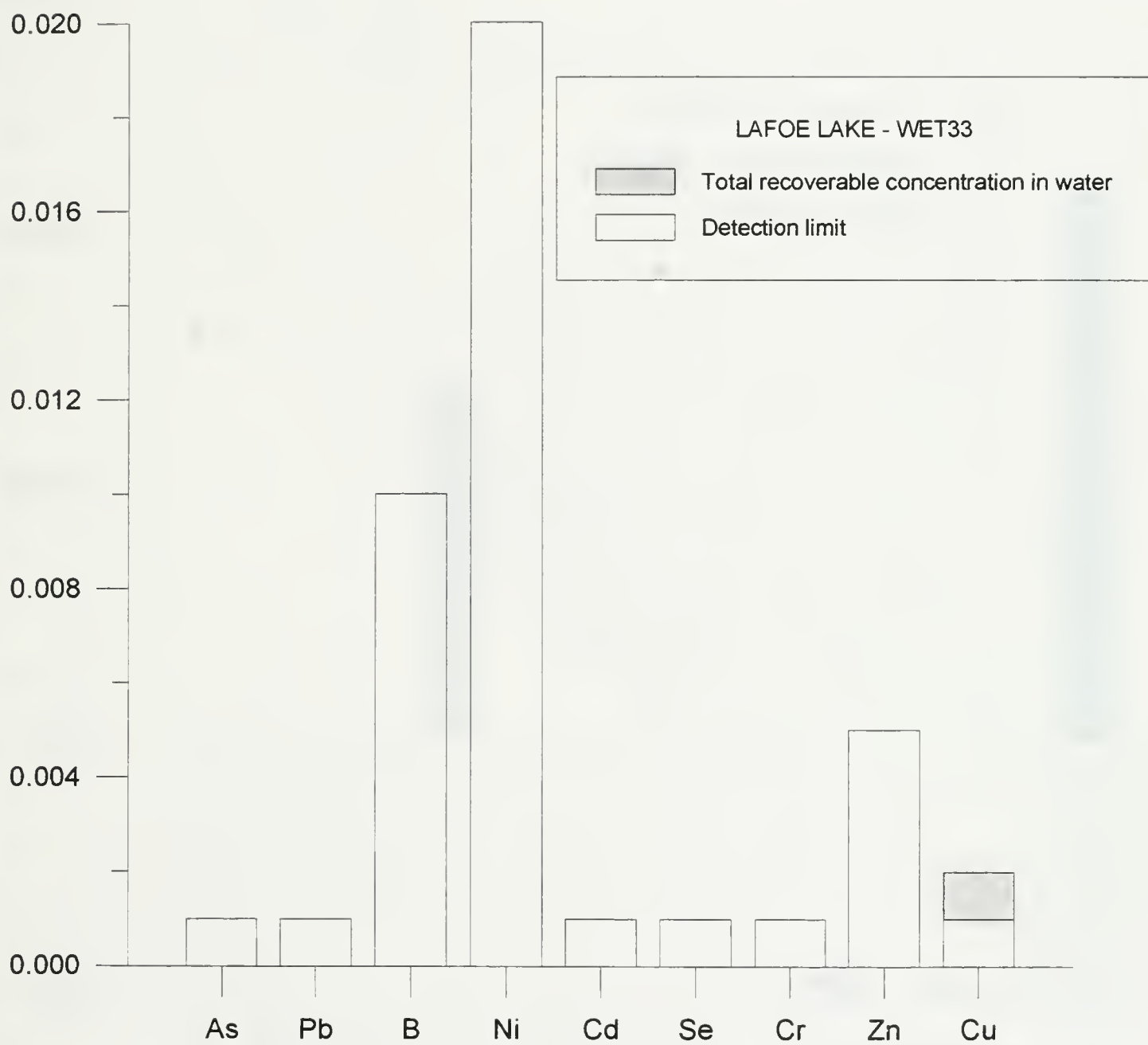
Annual Precipitation in Inches

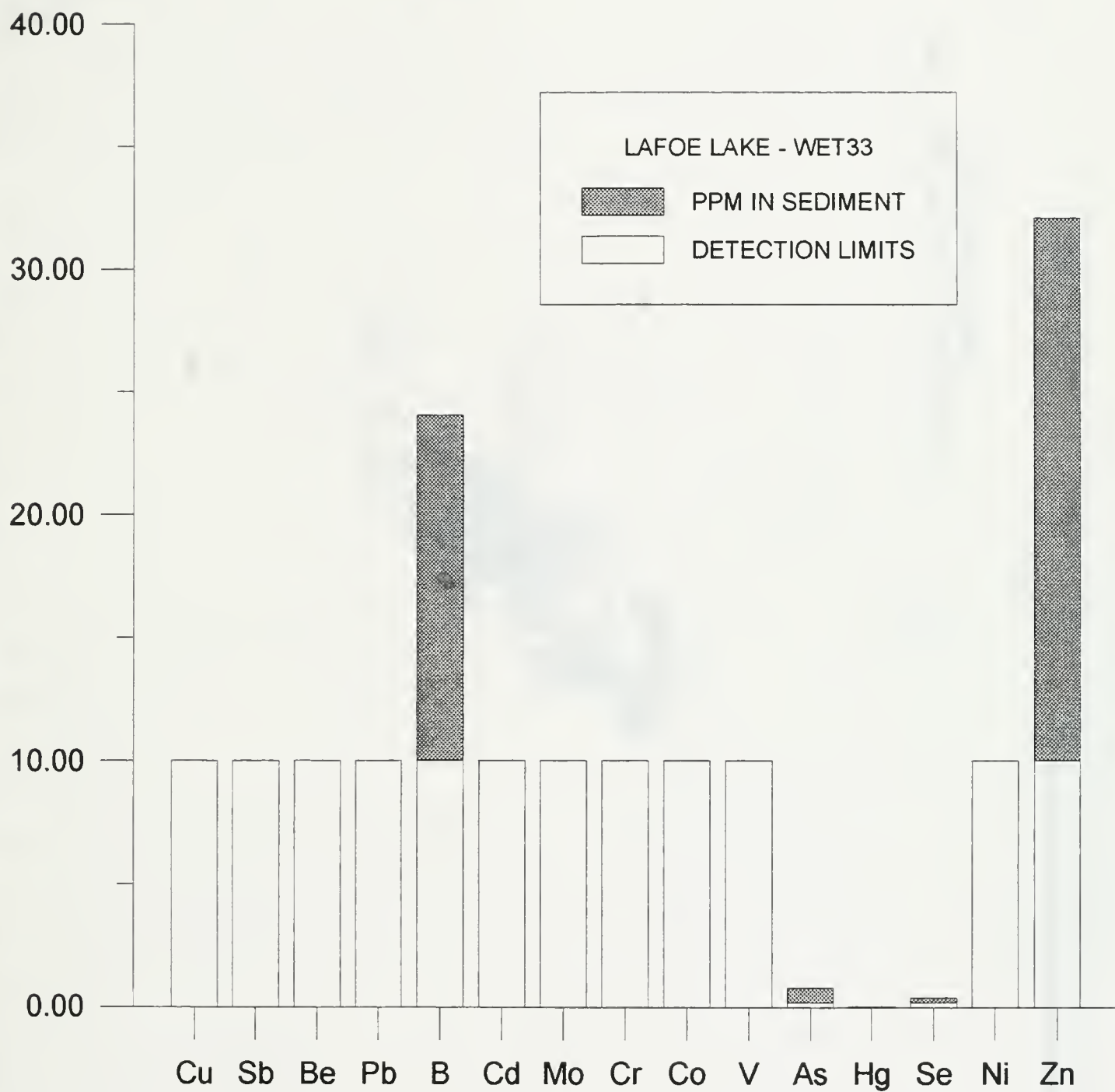


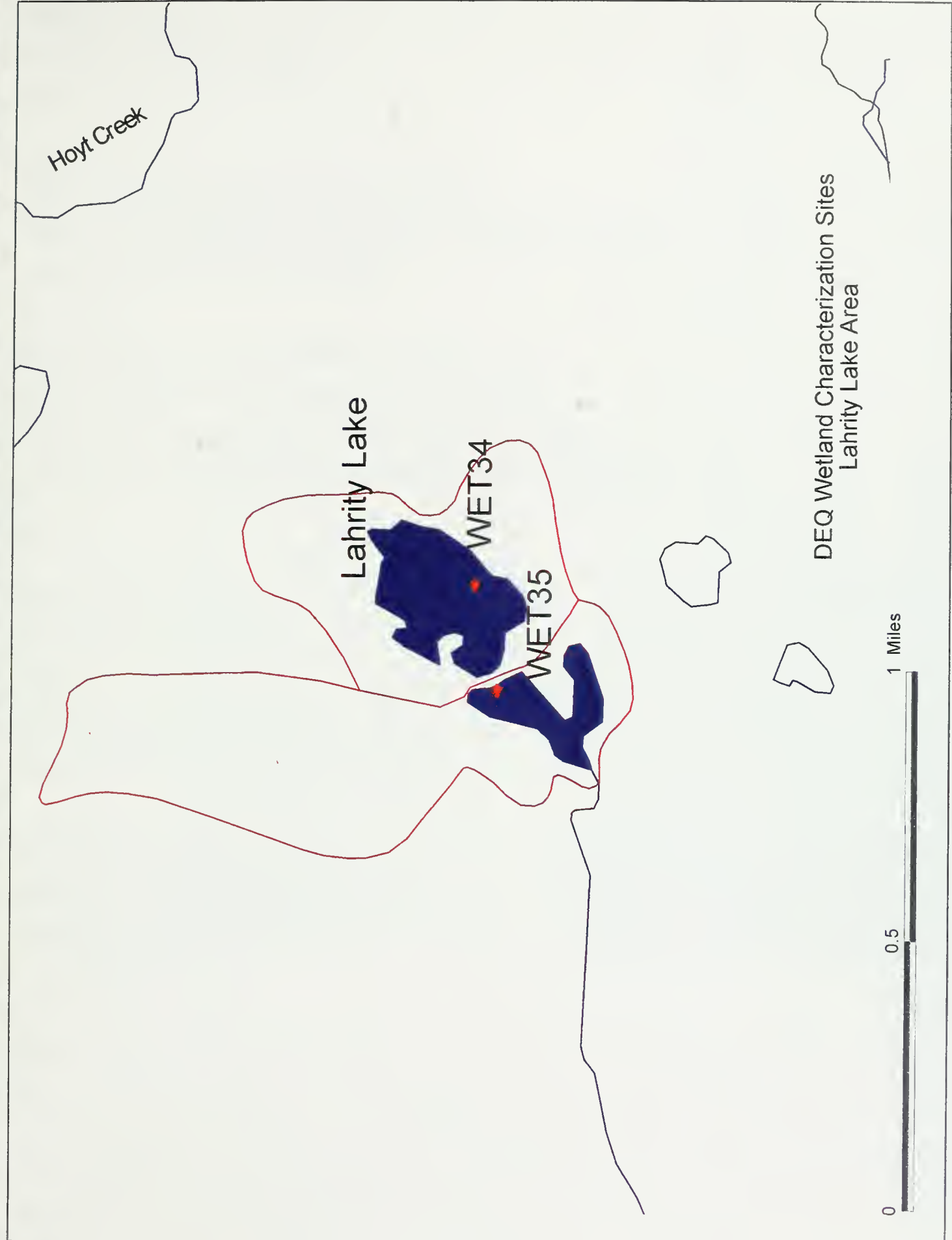
Monthly Mean, Maximum and Minimum Precipitation
Libby Ranger Station (number)



Concentrations in Milligrams per liter







Hoyt Creek

Lahurity Lake

WET34

WET35

DEQ Wetland Characterization Sites
Lahurity Lake Area



Wetland: LAHRITY LAKE

Site Code: WET34

7.5 Minute Quad: Ovando

Lat: 47 1 23

Long: 113 10 55

Mean Annual Precipitation in Inches:	15.00
Mean Annual Potential Evaporation (Penman) in Inches:	32.00
'Net Precipitation' in Inches:	-17.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

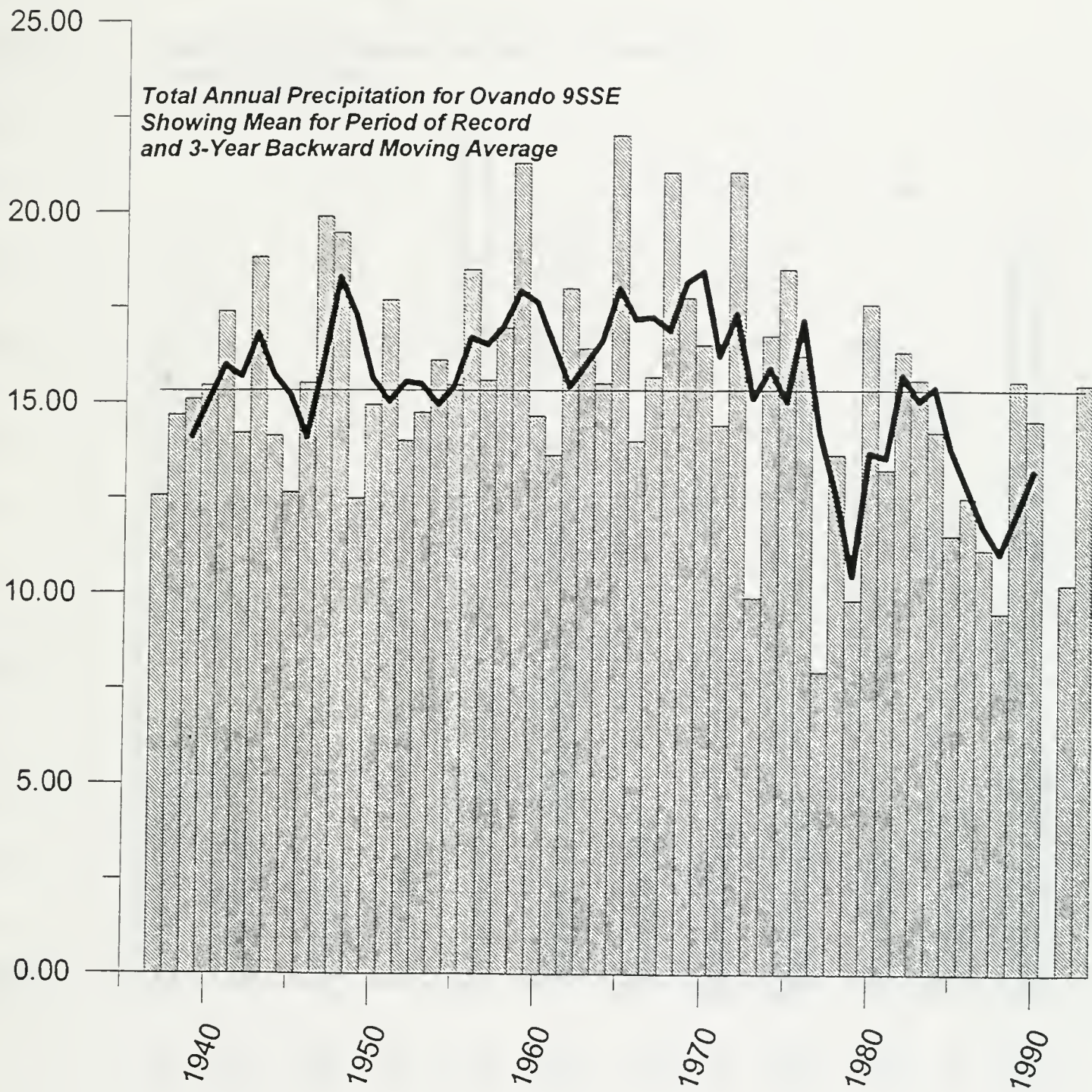
Site does not have known significant water imports.

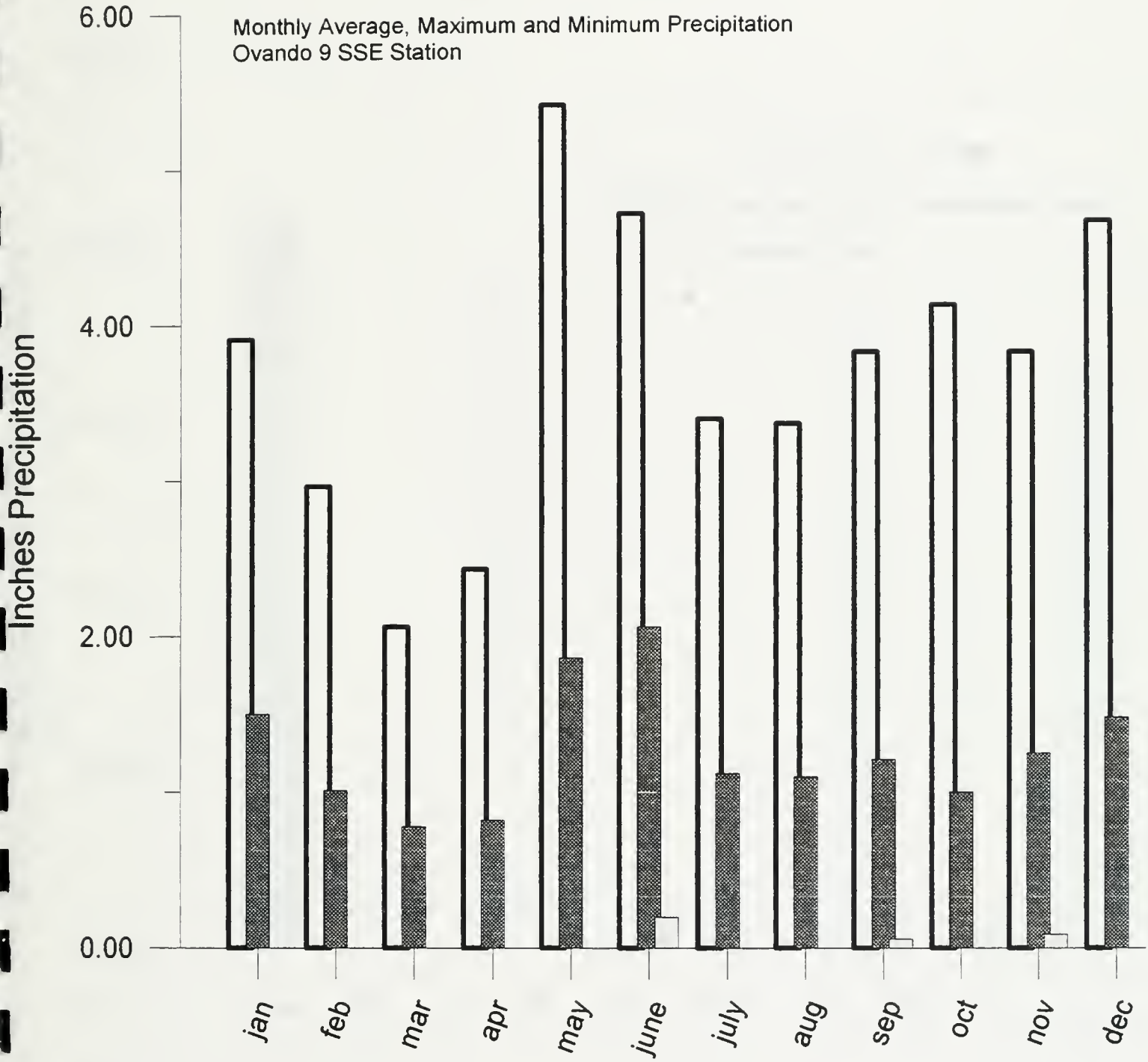
Mapped area of wetland:	32 acres
Area of contributing drainage basin:	120 acres
Mapped elevation of wetland surface:	4145 ft
Maximum elevation within drainage basin:	4440 ft
Net relief of contributing basin:	295 ft

COE Hydrogeomorphic class:	FRINGE
Primary surficial geologic unit	112TILL
Primary bedrock geologic unit	400BELT

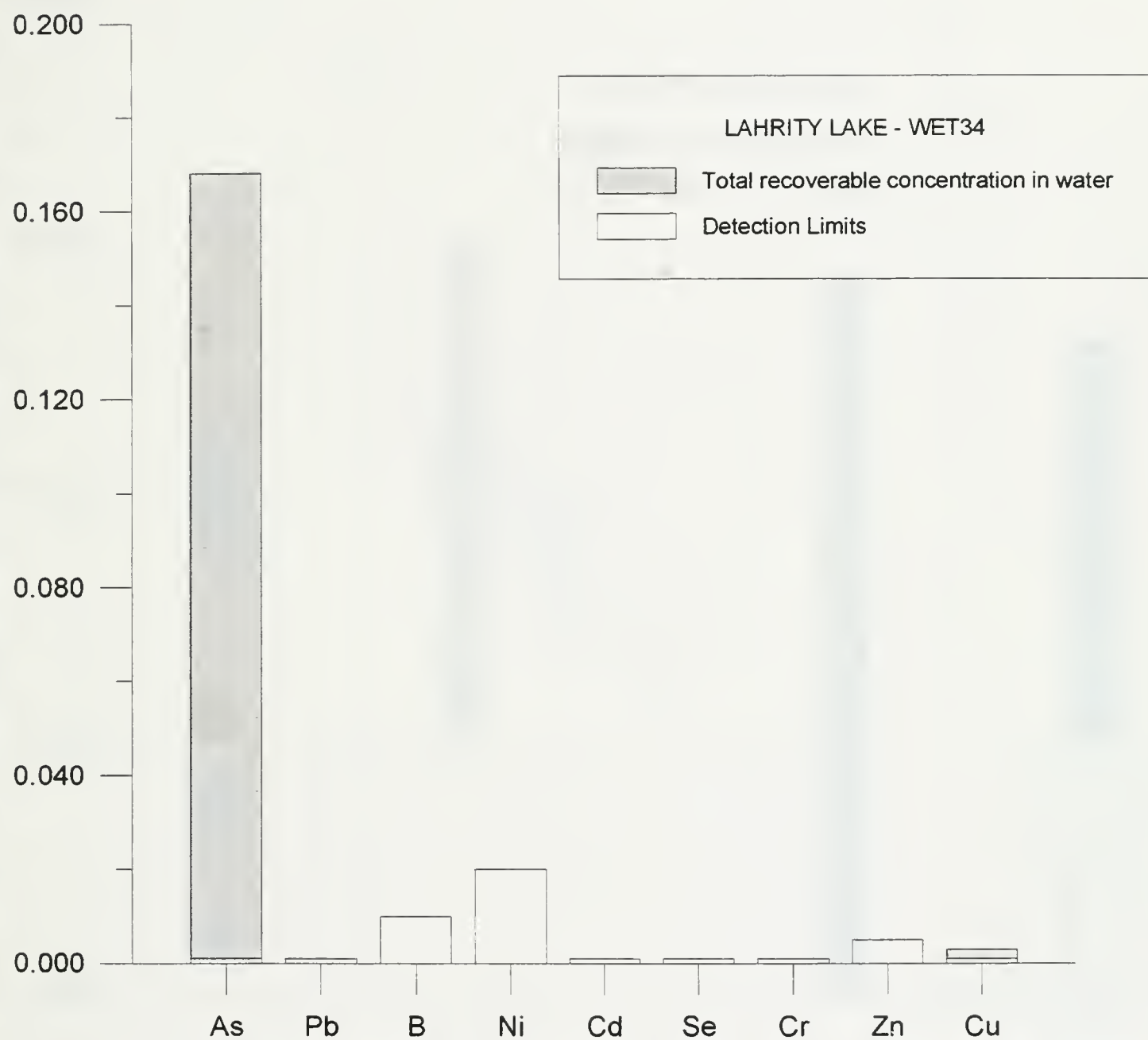
*Total Annual Precipitation for Ovando 9SSE
Showing Mean for Period of Record
and 3-Year Backward Moving Average*

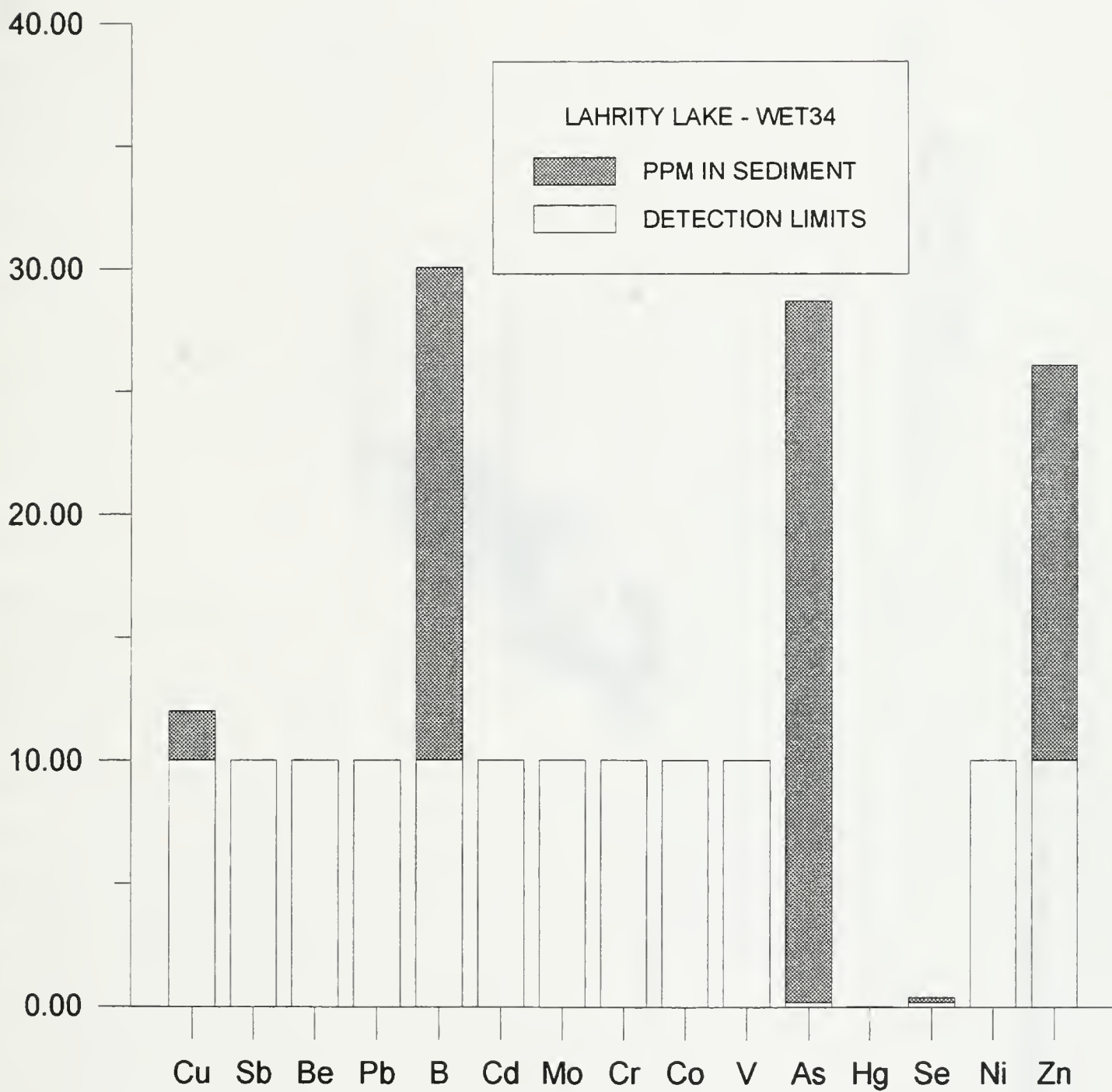
Annual Precipitation in Inches

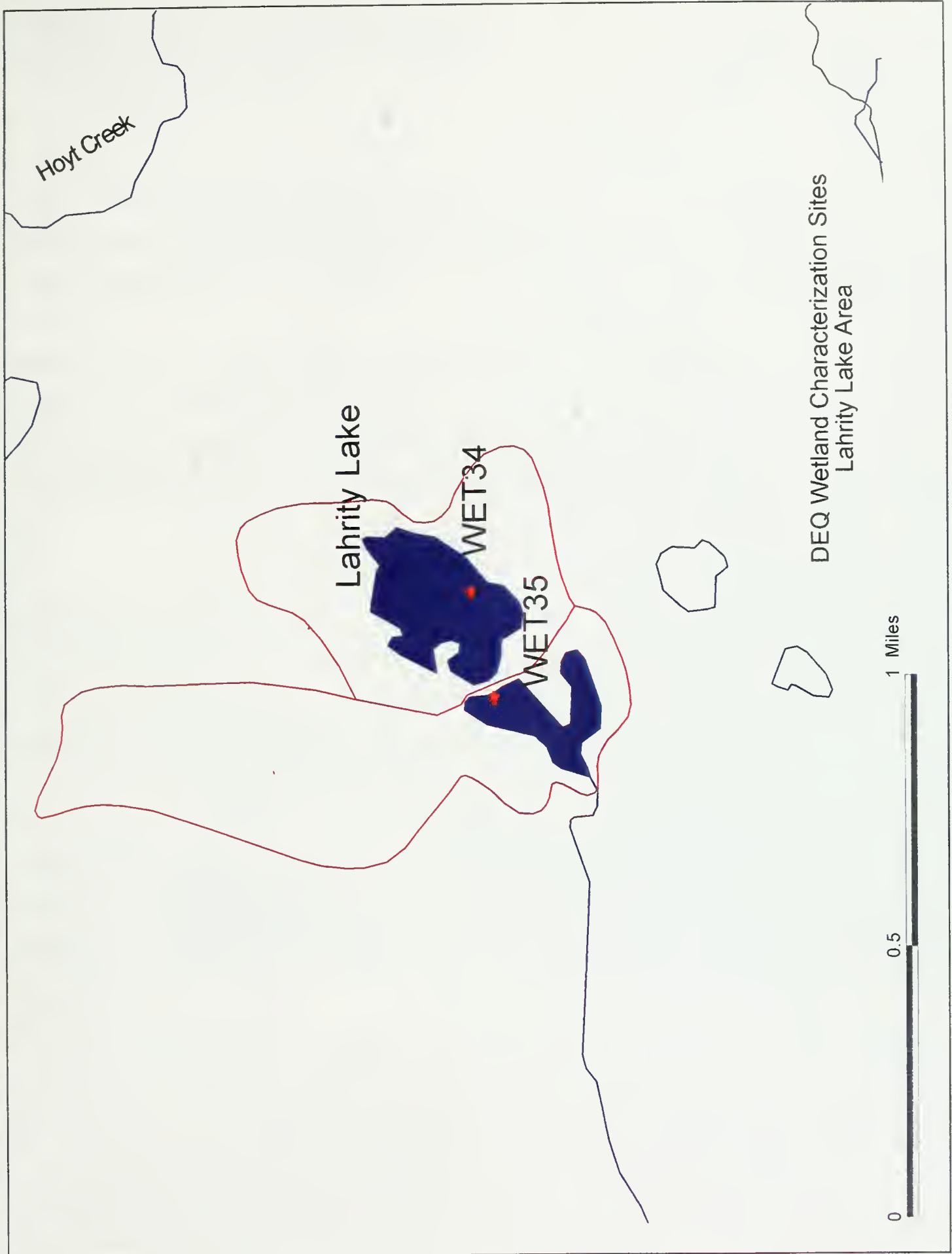




Concentrations in Milligrams per liter







Hoyt Creek

Lahurity Lake

WET34

WET35

DEQ Wetland Characterization Sites
Lahurity Lake Area

1 Miles

0.5

0

Wetland: LAHRITY LAKE SOUTH WETLAND

Site Code: WET35

7.5 Minute Quad: Ovando

Lat: 47 1 20

Long: 113 11 15

Mean Annual Precipitation in Inches:	15.00
Mean Annual Potential Evaporation (Penman) in Inches:	32.00
'Net Precipitation' in Inches:	-17.00

Site does not have a mapped surface inlet.

Site has a mapped surface outlet.

Site is not known to be artificially impounded.

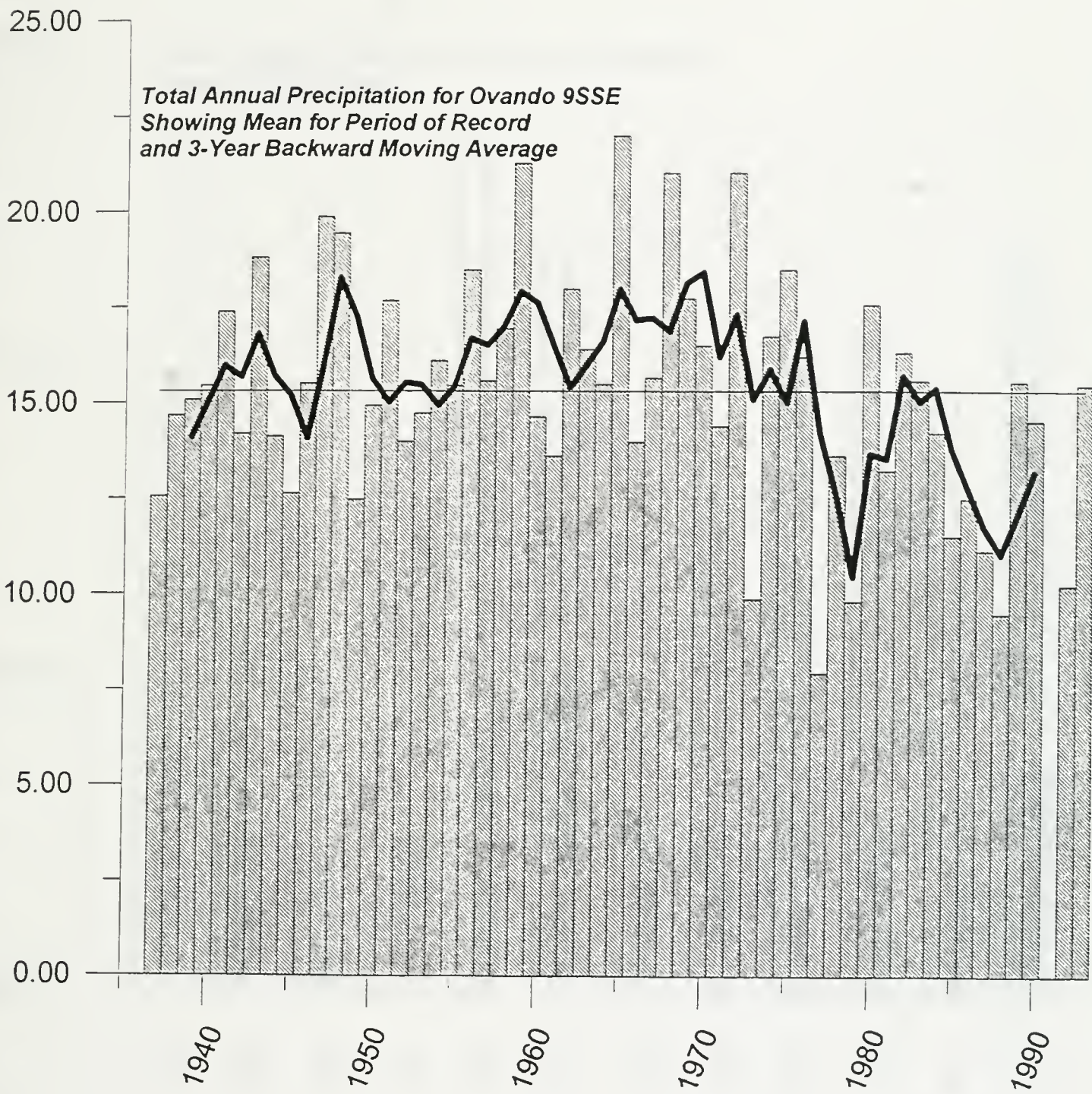
Site does not have known significant water imports.

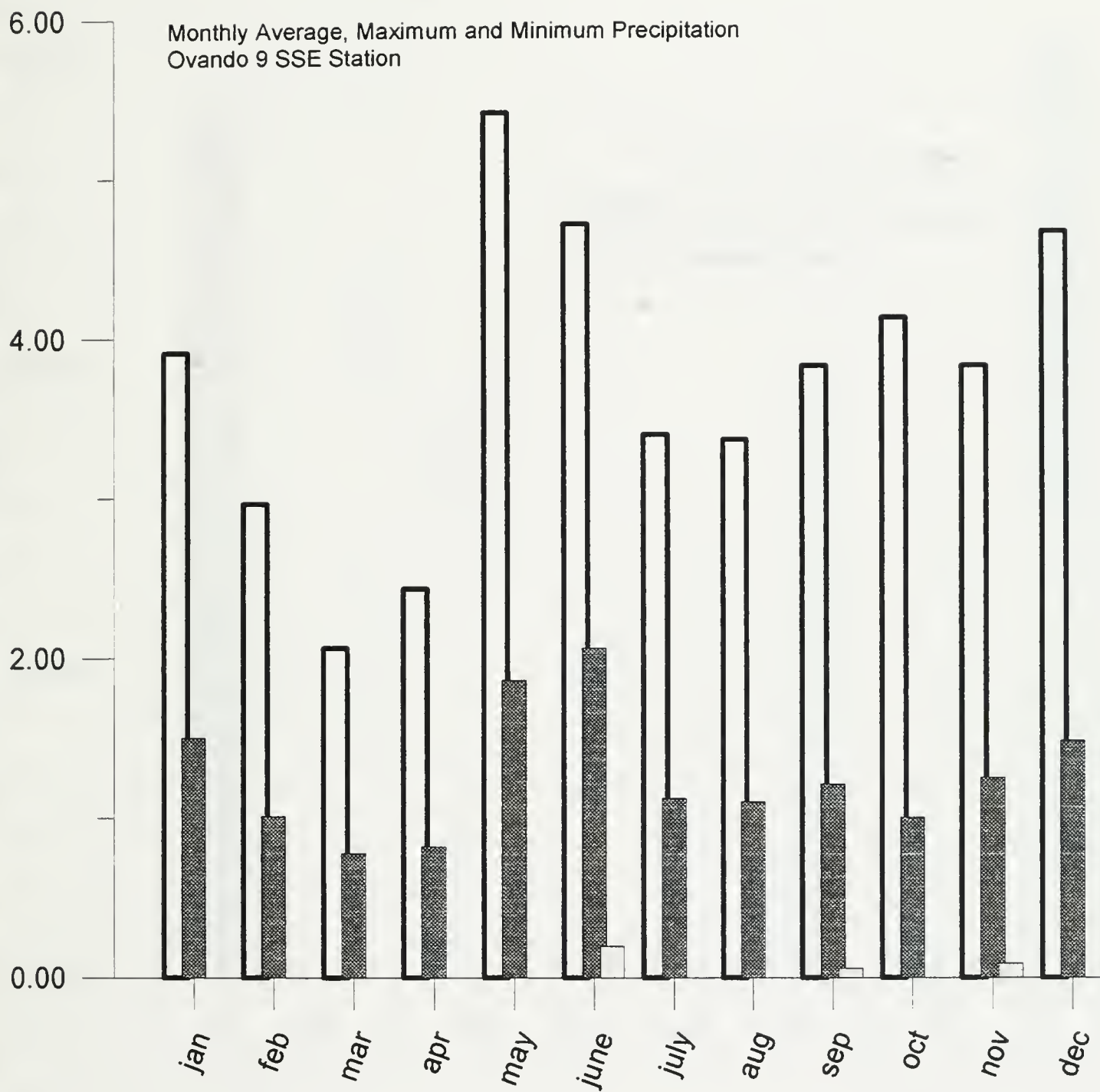
Mapped area of wetland:	14 acres
Area of contributing drainage basin:	170 acres
Mapped elevation of wetland surface:	4155 ft
Maximum elevation within drainage basin:	4565 ft
Net relief of contributing basin:	410 ft

COE Hydrogeomorphic class:	DEPRESSIONAL
Primary surficial geologic unit	112TILL
Primary bedrock geologic unit	400BELT

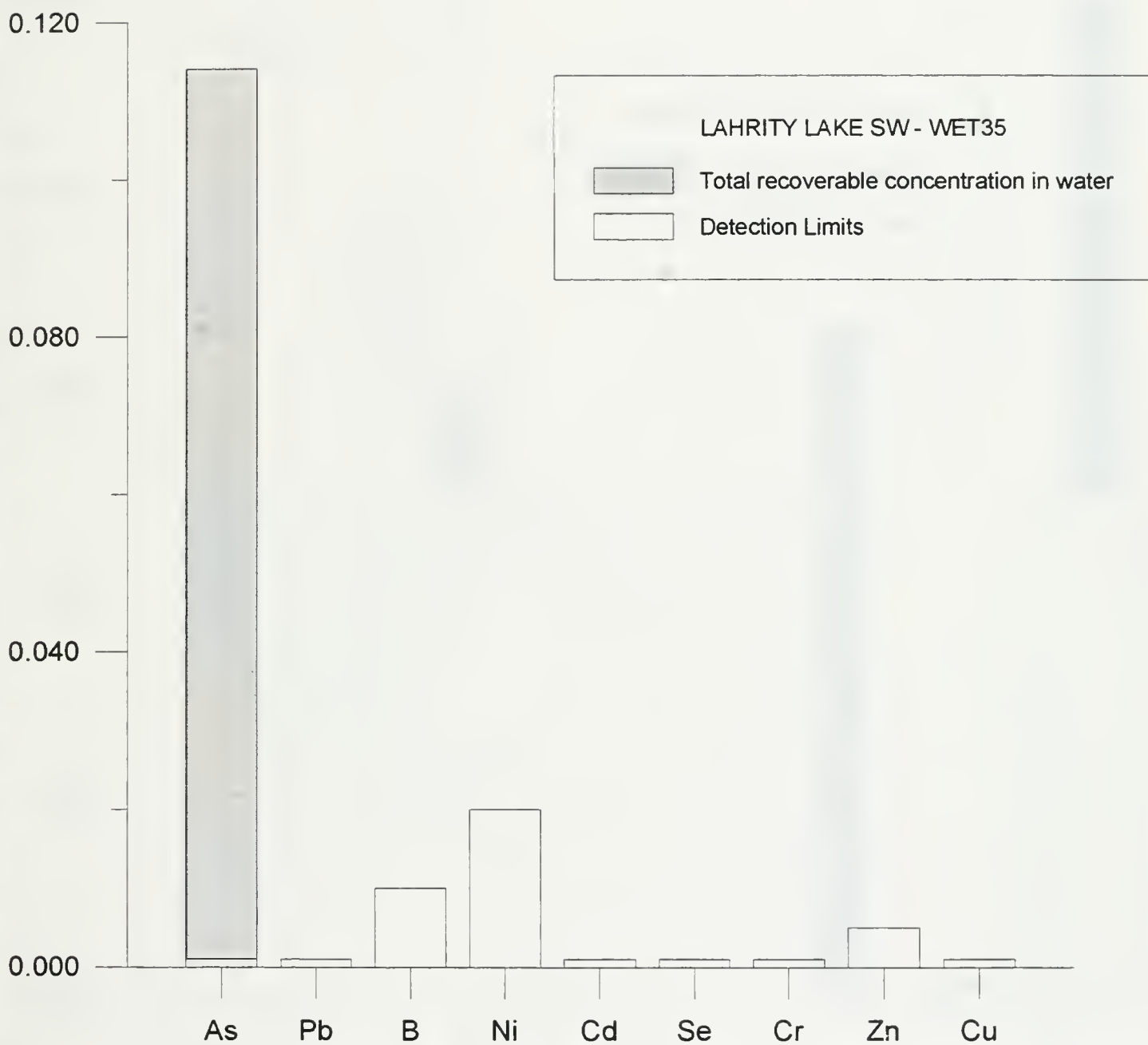
Annual Precipitation in Inches

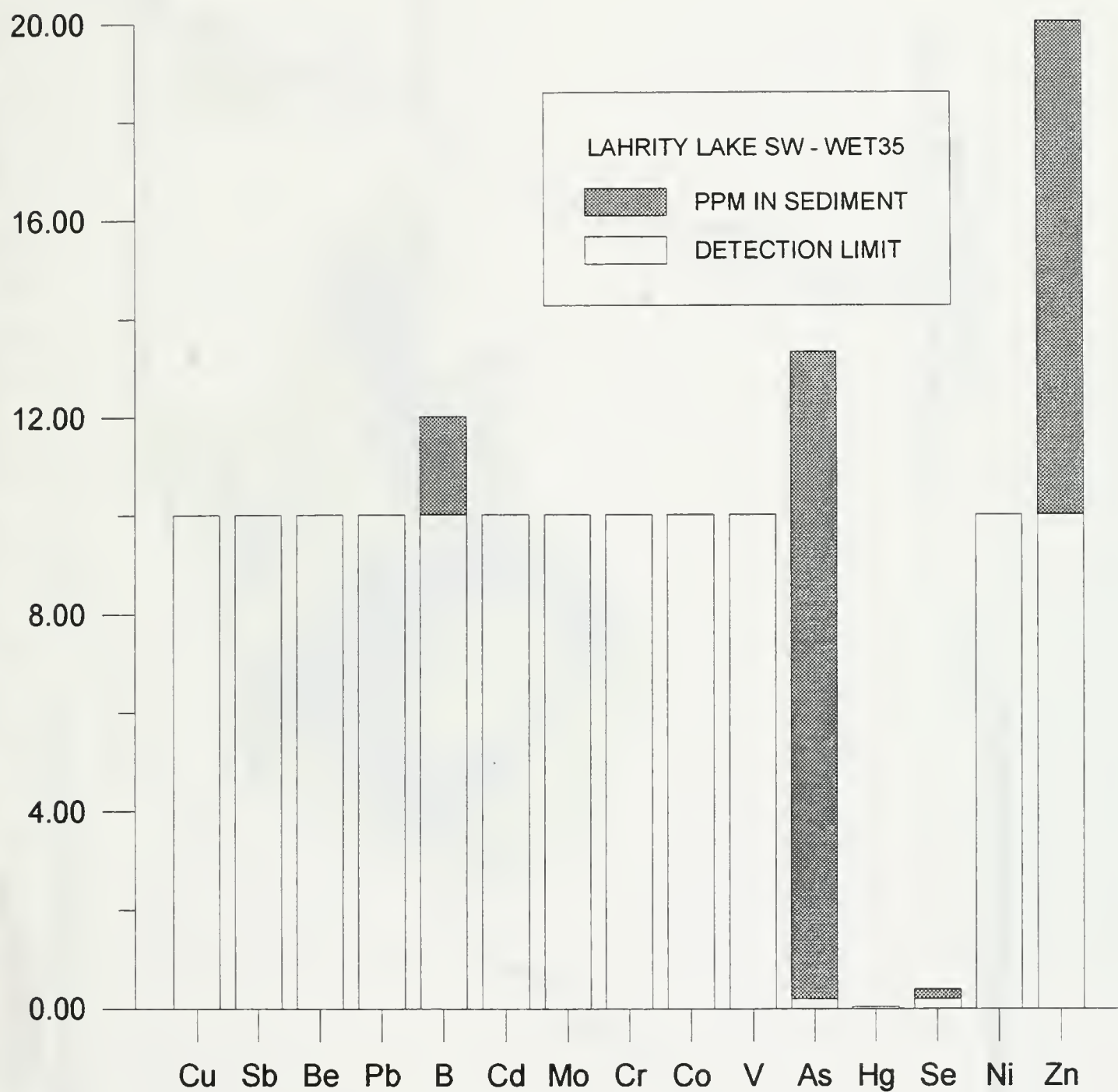
*Total Annual Precipitation for Ovando 9SSE
Showing Mean for Period of Record
and 3-Year Backward Moving Average*

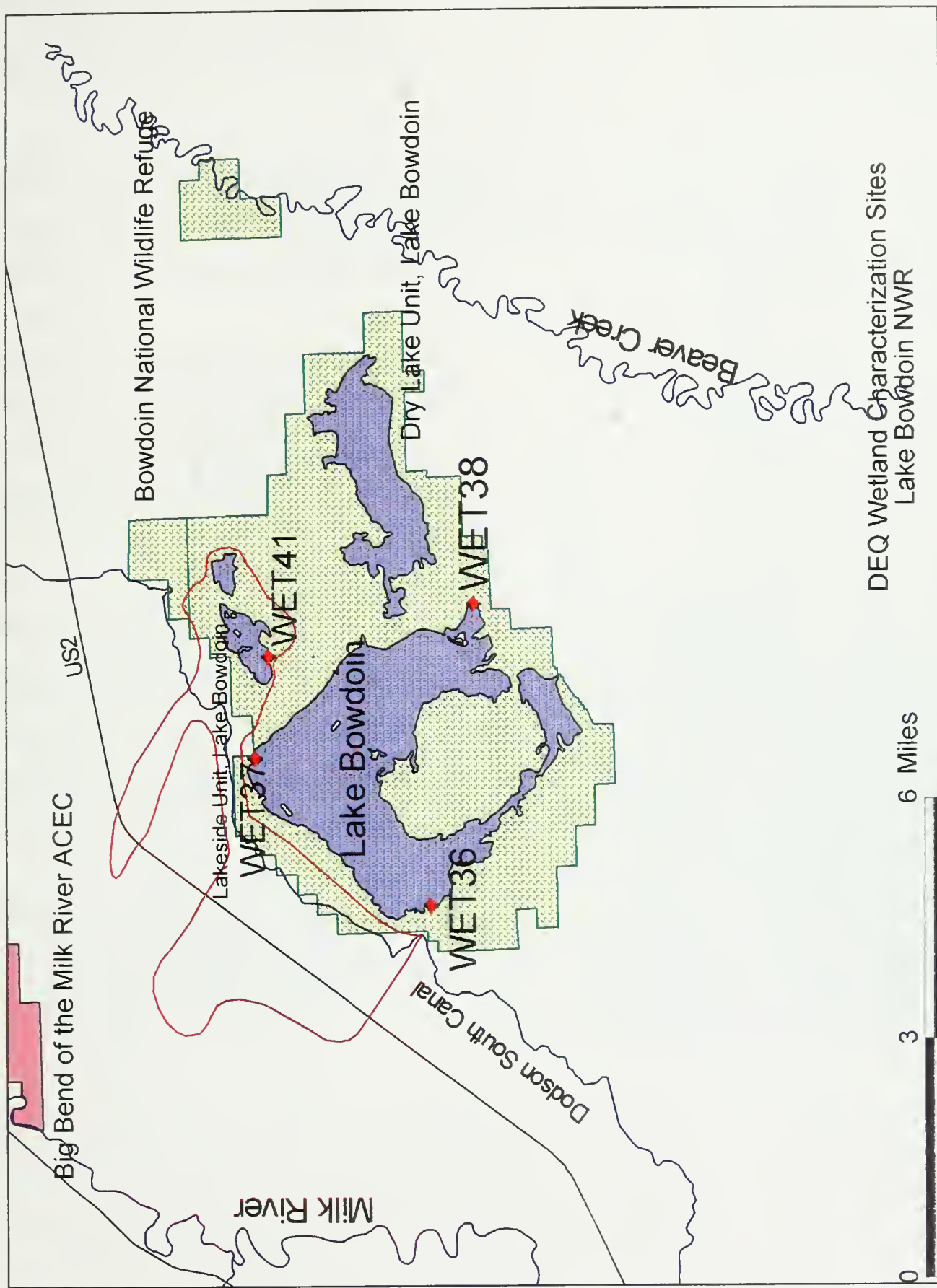




Concentrations in Milligrams per liter







Wetland: LAKE BOWDOIN INLET

Site Code: WET36

7.5 Minute Quad: LAKE BOWDOIN

Lat: 48 23 45

Long: 107 43 25

Mean Annual Precipitation in Inches: 11.00

Mean Annual Potential Evaporation (Penman) in Inches: 39.00

'Net Precipitation' in Inches: -28.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is artificially impounded.

Site has significant water imports.

Mapped area of wetland: 3933 acres

Area of contributing drainage basin: 7166000 acres

Mapped elevation of wetland surface: 2209 ft

Maximum elevation within drainage basin: 2625 ft

Net relief of contributing basin: 416 ft

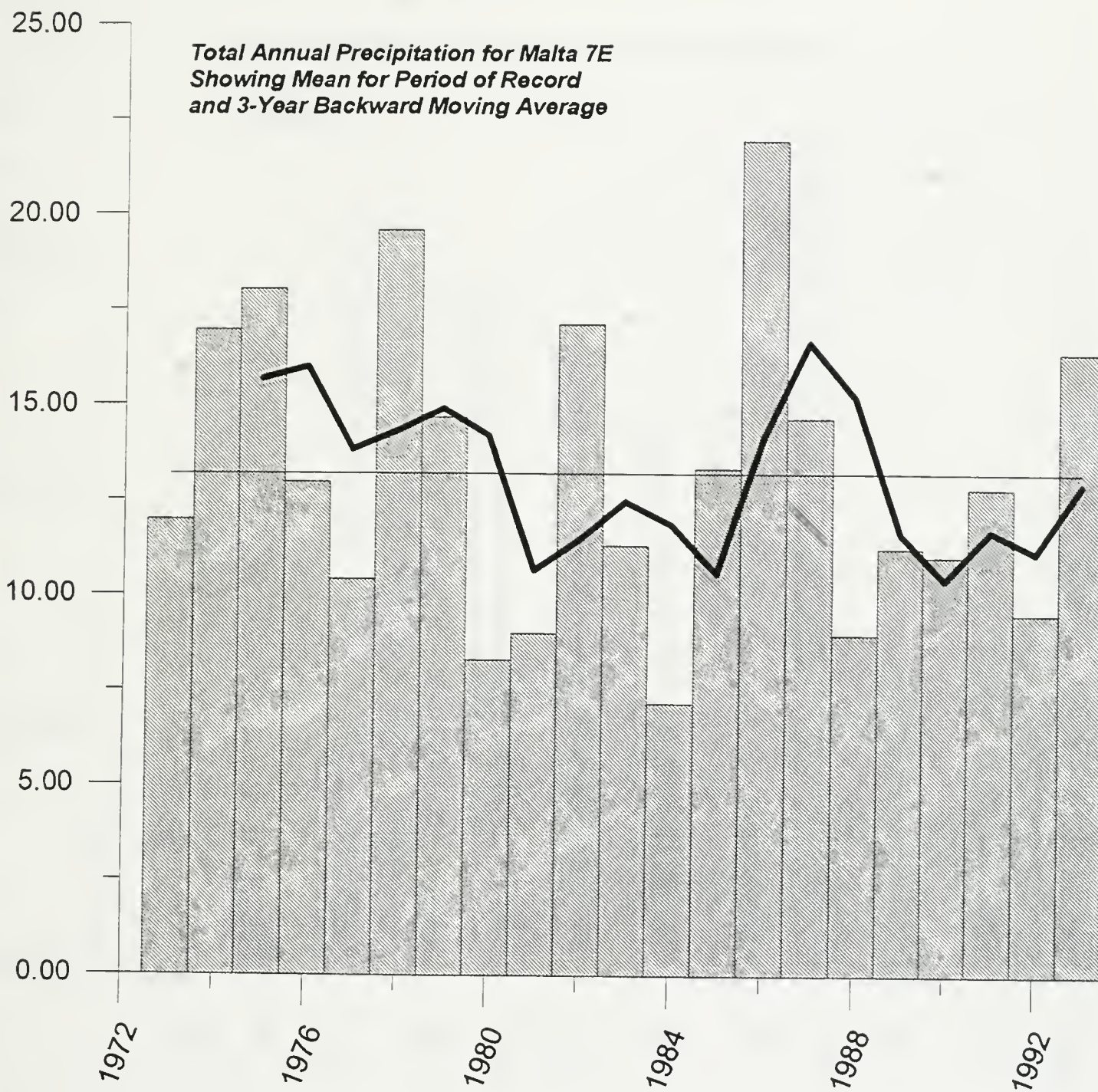
COE Hydrogeomorphic class: FRINGE

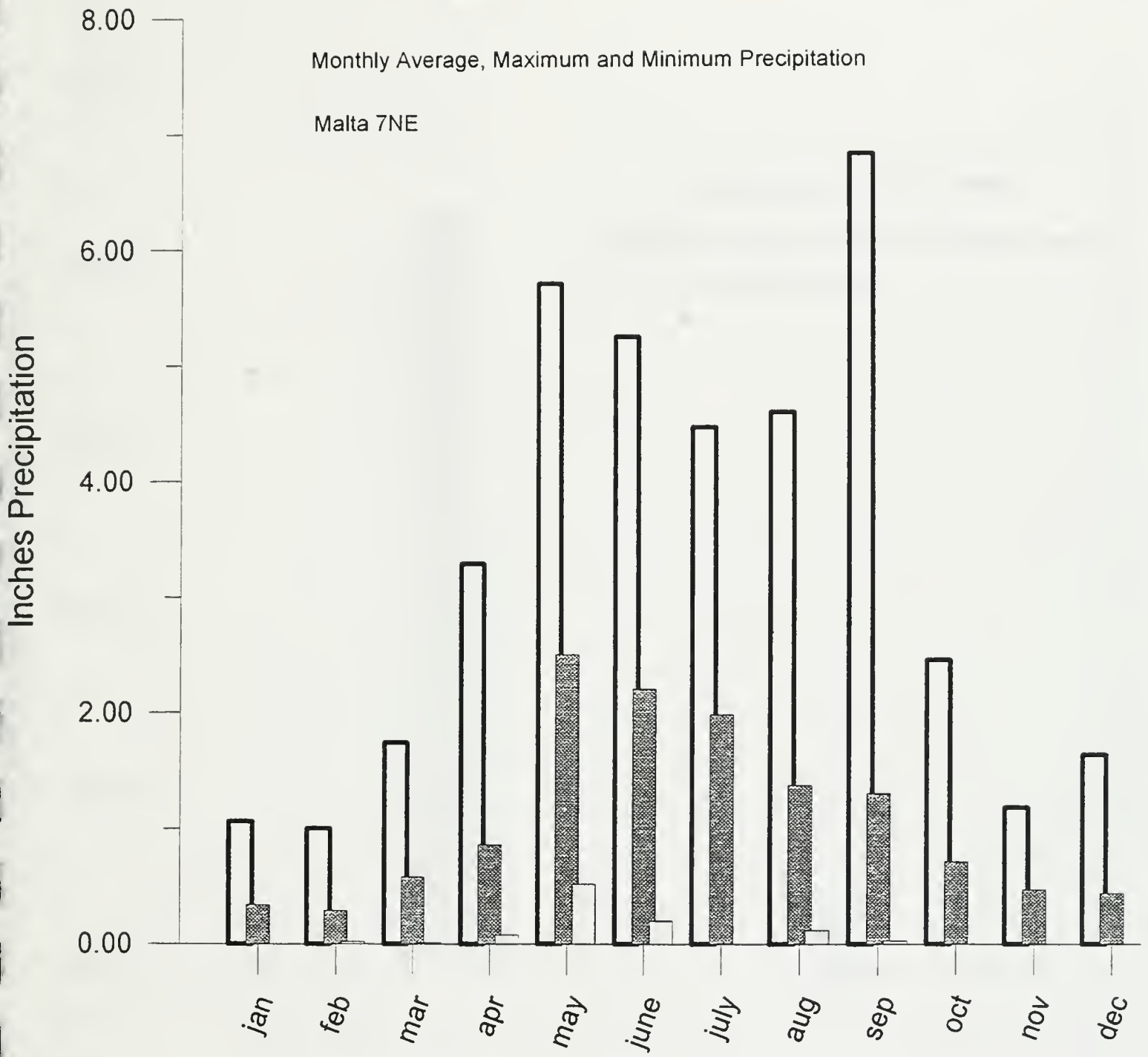
Primary surficial geologic unit 110"LAC"

Primary bedrock geologic unit 211CLGG

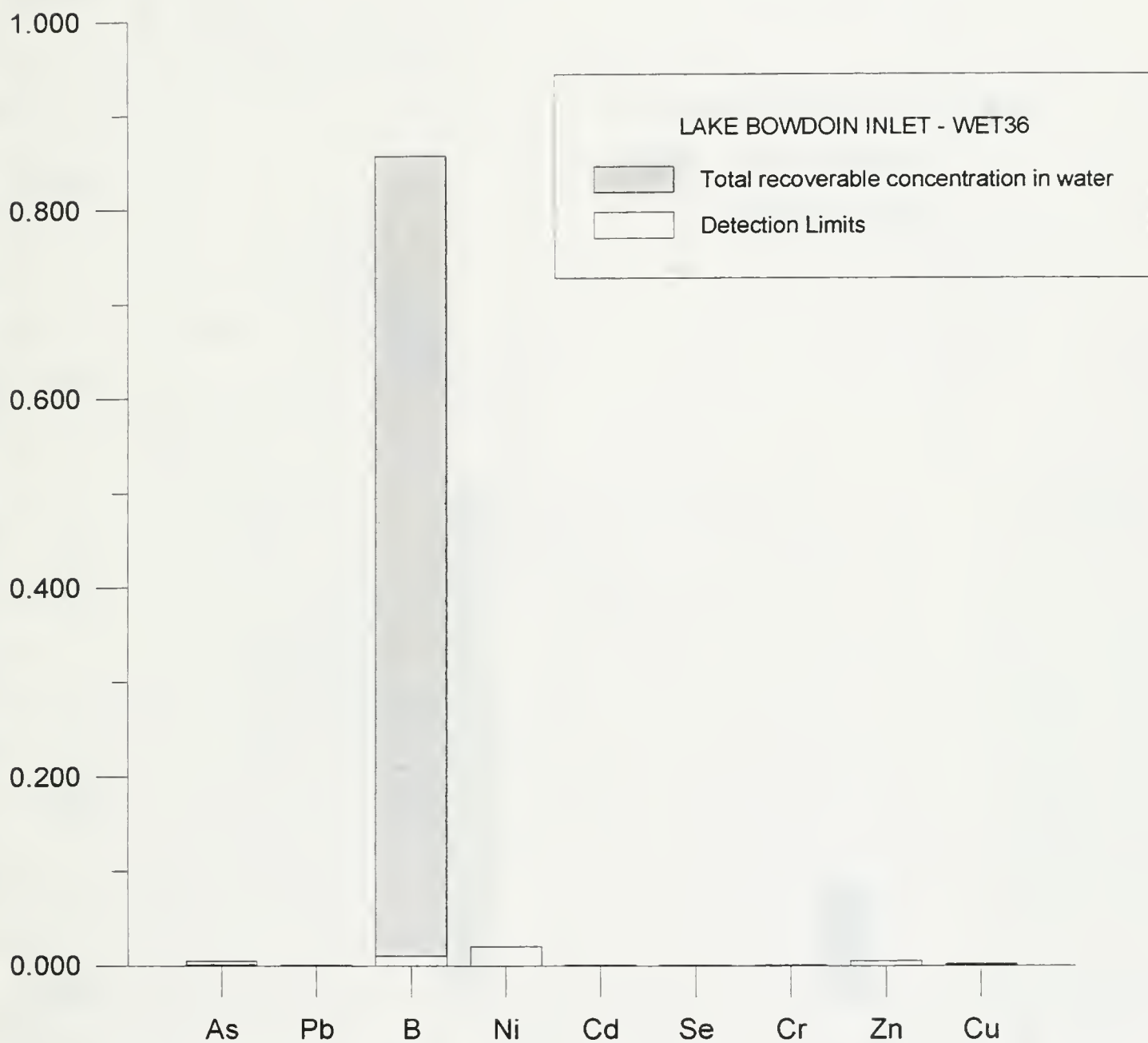
Annual Precipitation in Inches

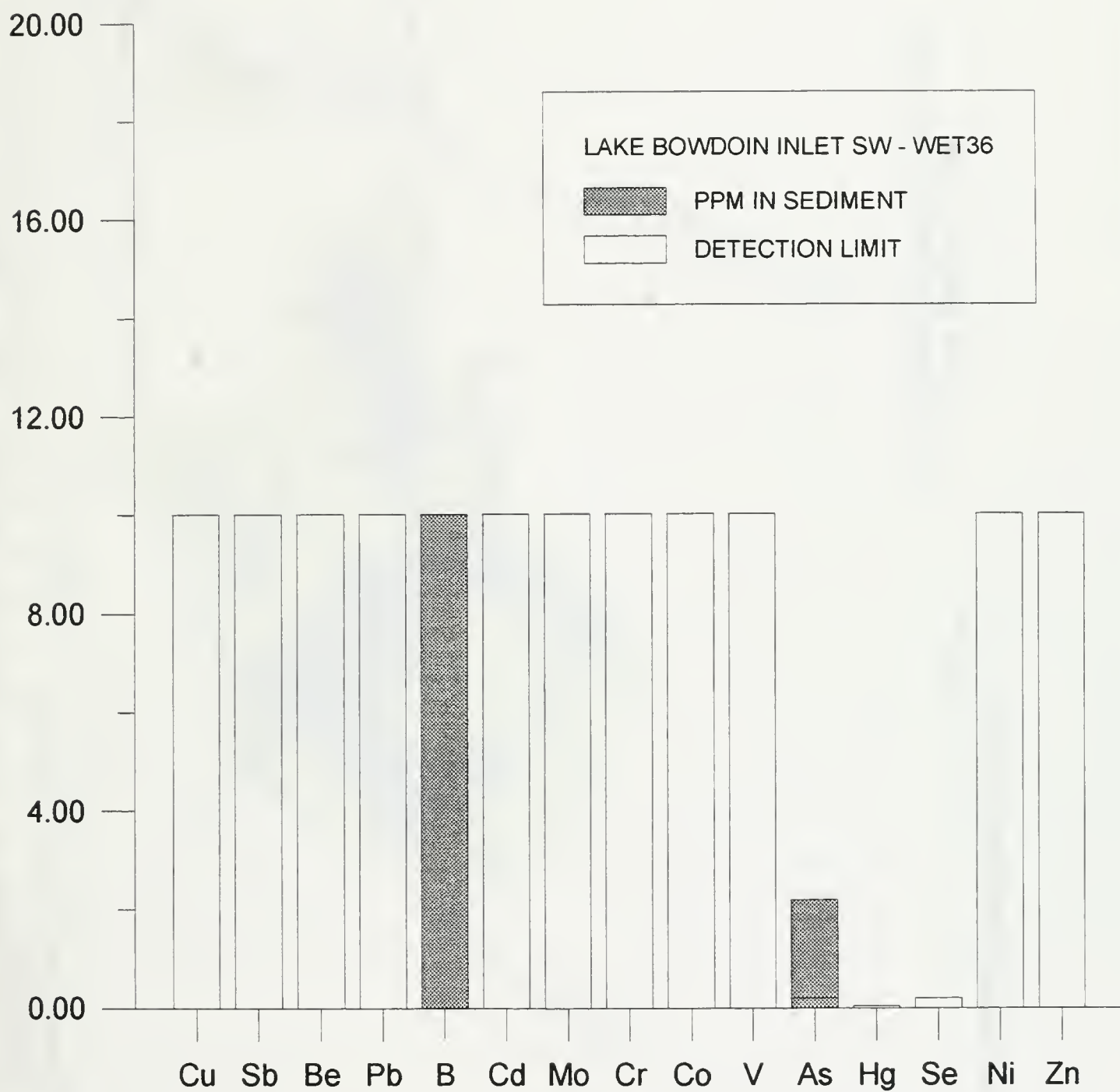
*Total Annual Precipitation for Malta 7E
Showing Mean for Period of Record
and 3-Year Backward Moving Average*

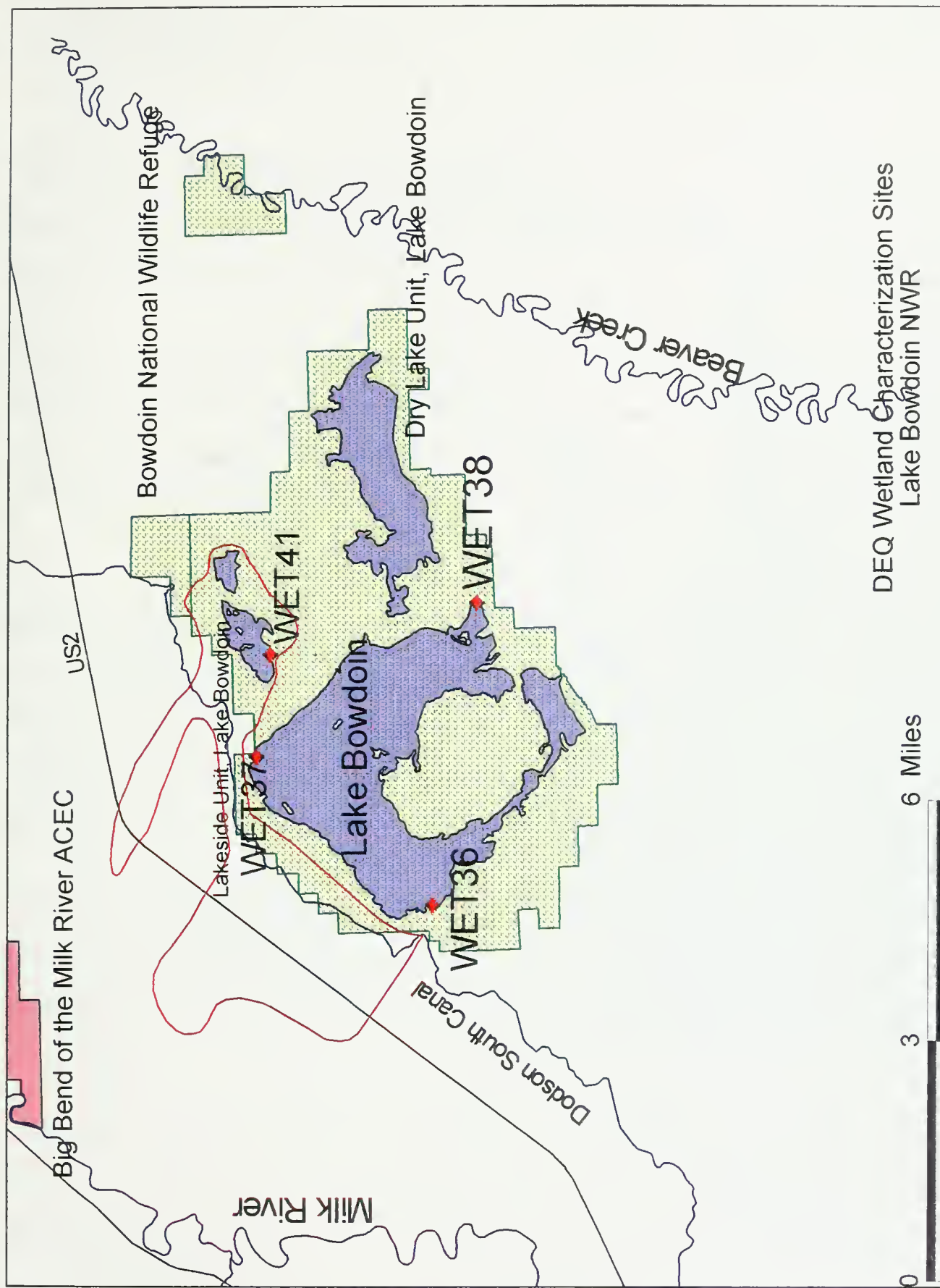




Concentrations in Milligrams per liter







Wetland: LAKE BOWDOIN NORTH SHORE

Site Code: WET37

7.5 Minute Quad: LAKE BOWDOIN

Lat: 48 25 40

Long: 107 41 0

Mean Annual Precipitation in Inches:	11.00
Mean Annual Potential Evaporation (Penman) in Inches:	39.00
'Net Precipitation' in Inches:	-28.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is artificially impounded.

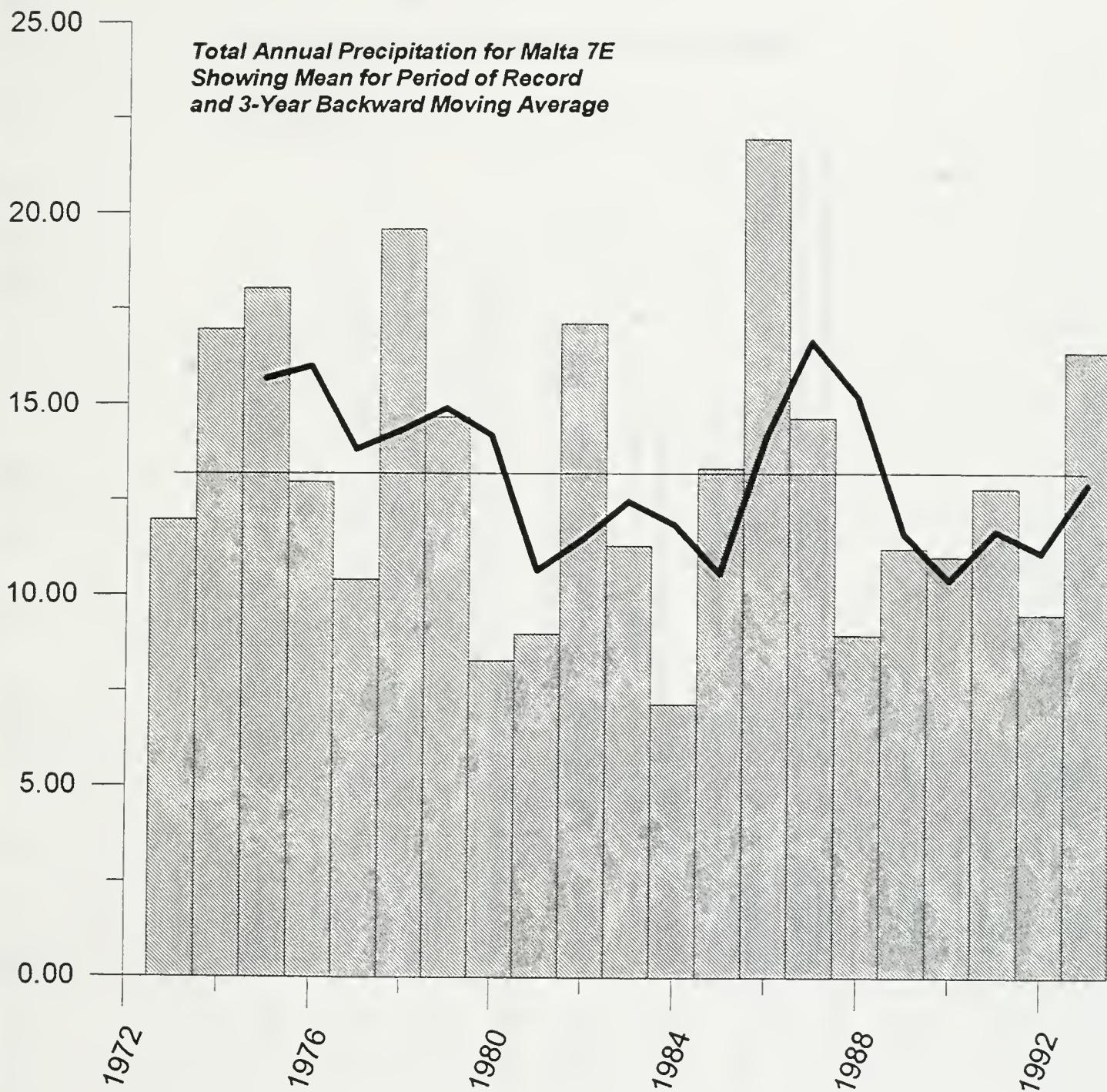
Site has significant water imports.

Mapped area of wetland:	3933 acres
Area of contributing drainage basin:	7166000 acres
Mapped elevation of wetland surface:	2209 ft
Maximum elevation within drainage basin:	2625 ft
Net relief of contributing basin:	416 ft

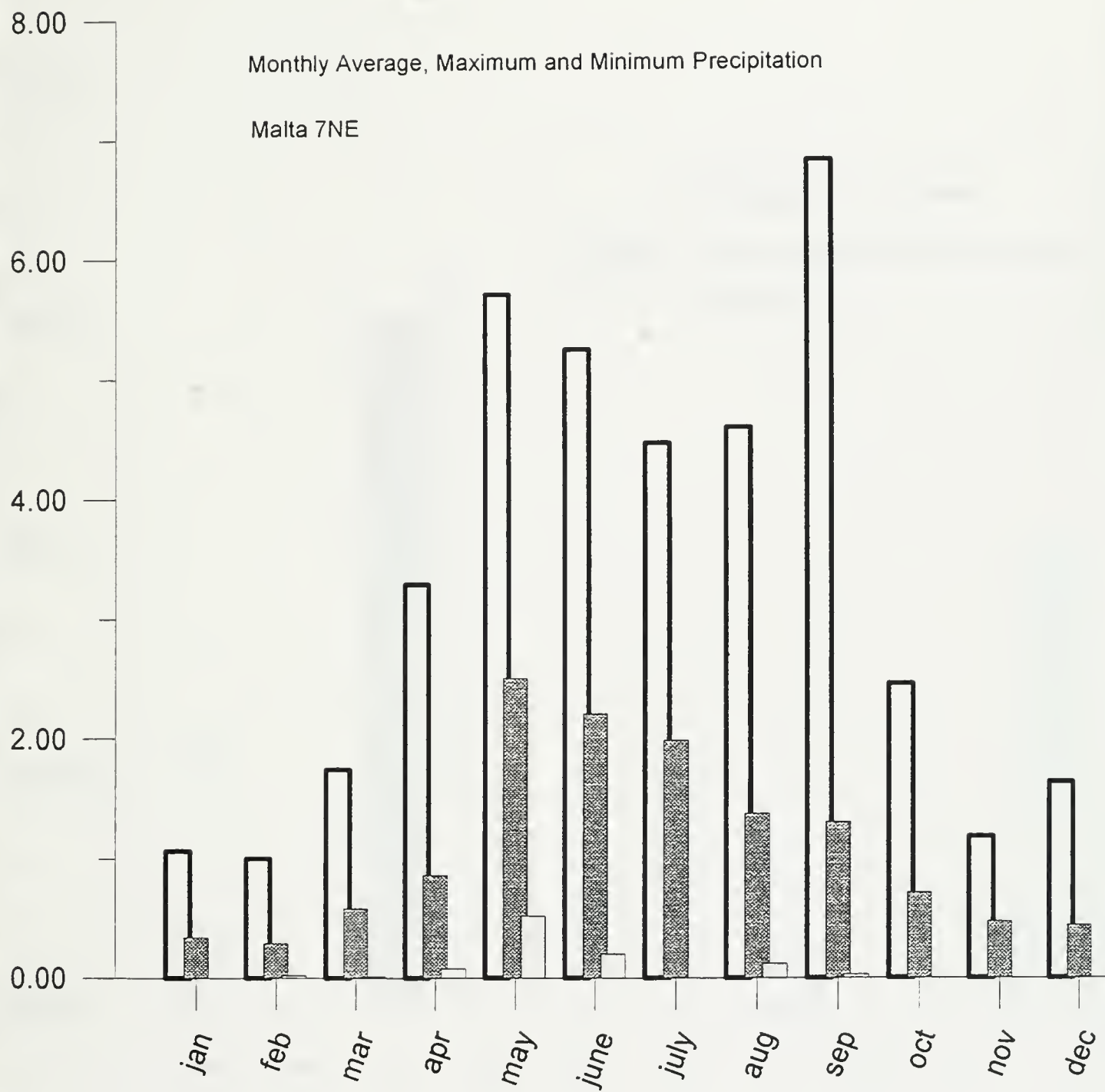
COE Hydrogeomorphic class:	FRINGE
Primary surficial geologic unit	110"LAC"
Primary bedrock geologic unit	211CLGG

Annual Precipitation in Inches

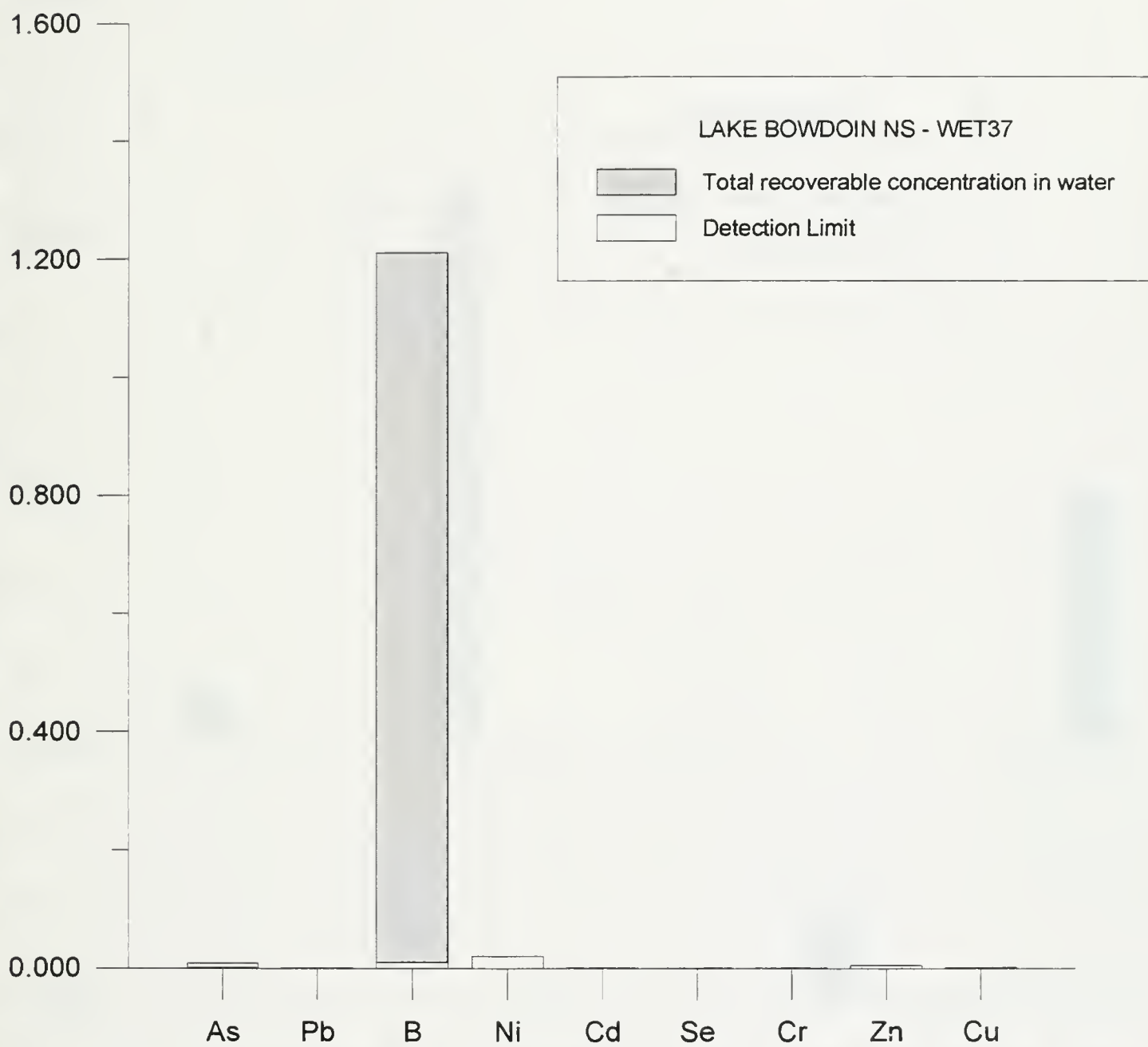
*Total Annual Precipitation for Malta 7E
Showing Mean for Period of Record
and 3-Year Backward Moving Average*

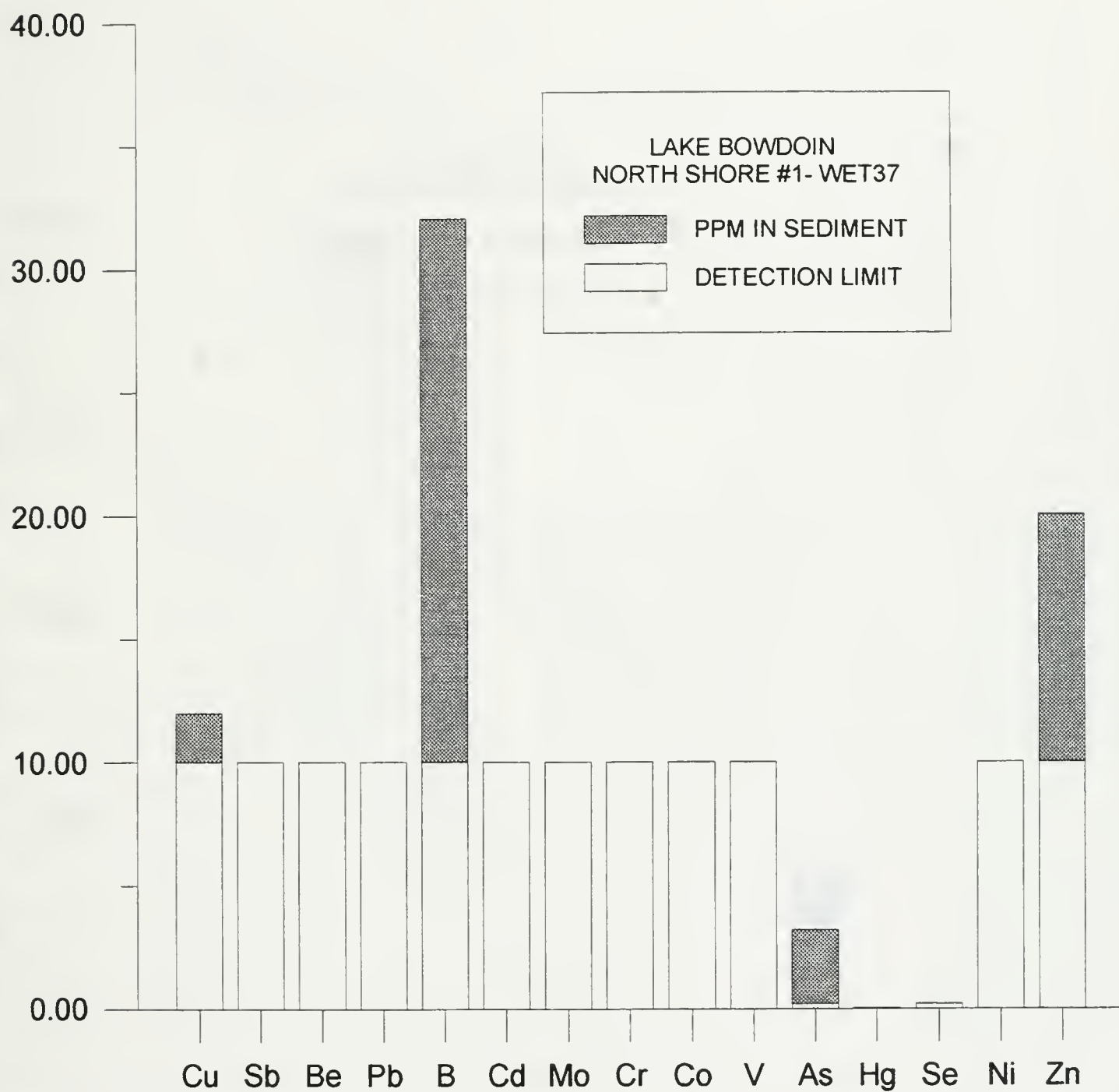


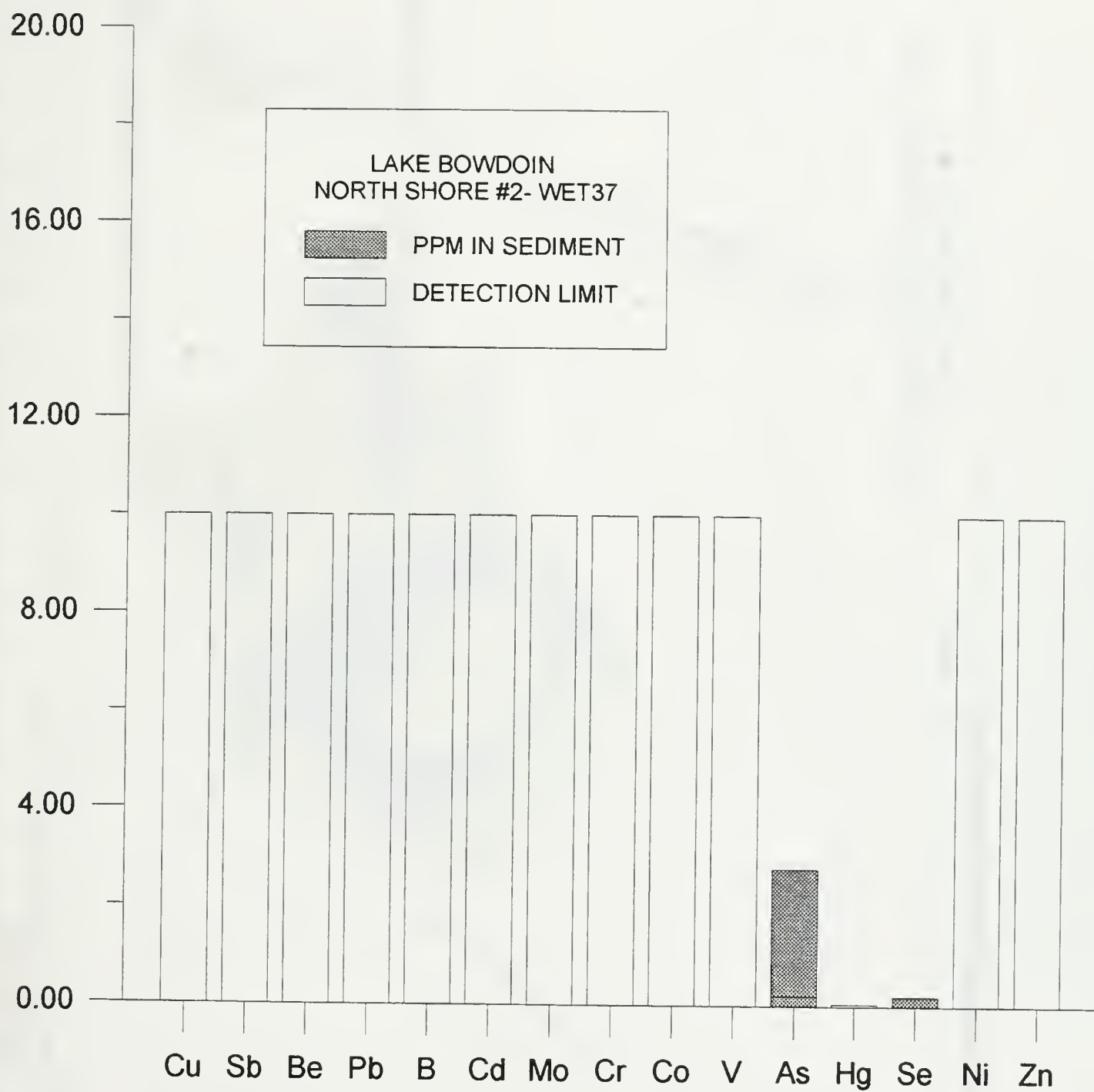
Inches Precipitation

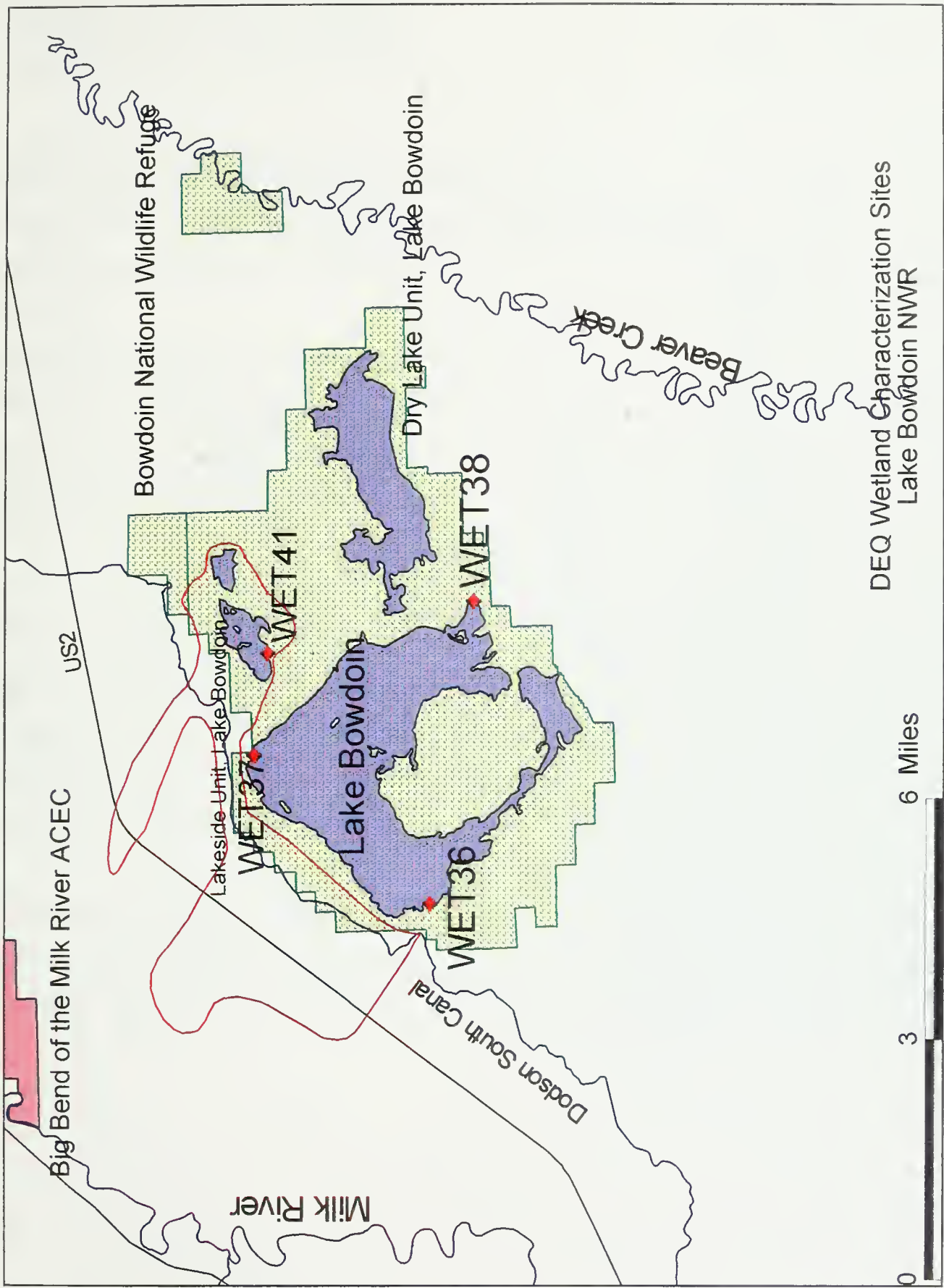


Concentrations in Milligrams per liter









Wetland: LAKE BOWDOIN OUTLET

Site Code: WET38

7.5 Minute Quad: LAKE BOWDOIN

Lat: 48 23 10

Long: 107 38 33

Mean Annual Precipitation in Inches: 11.00

Mean Annual Potential Evaporation (Penman) in Inches: 39.00

'Net Precipitation' in Inches: -28.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is artificially impounded.

Site has significant water imports.

Mapped area of wetland: 3933 acres

Area of contributing drainage basin: 7166000 acres

Mapped elevation of wetland surface: 2209 ft

Maximum elevation within drainage basin: 2625 ft

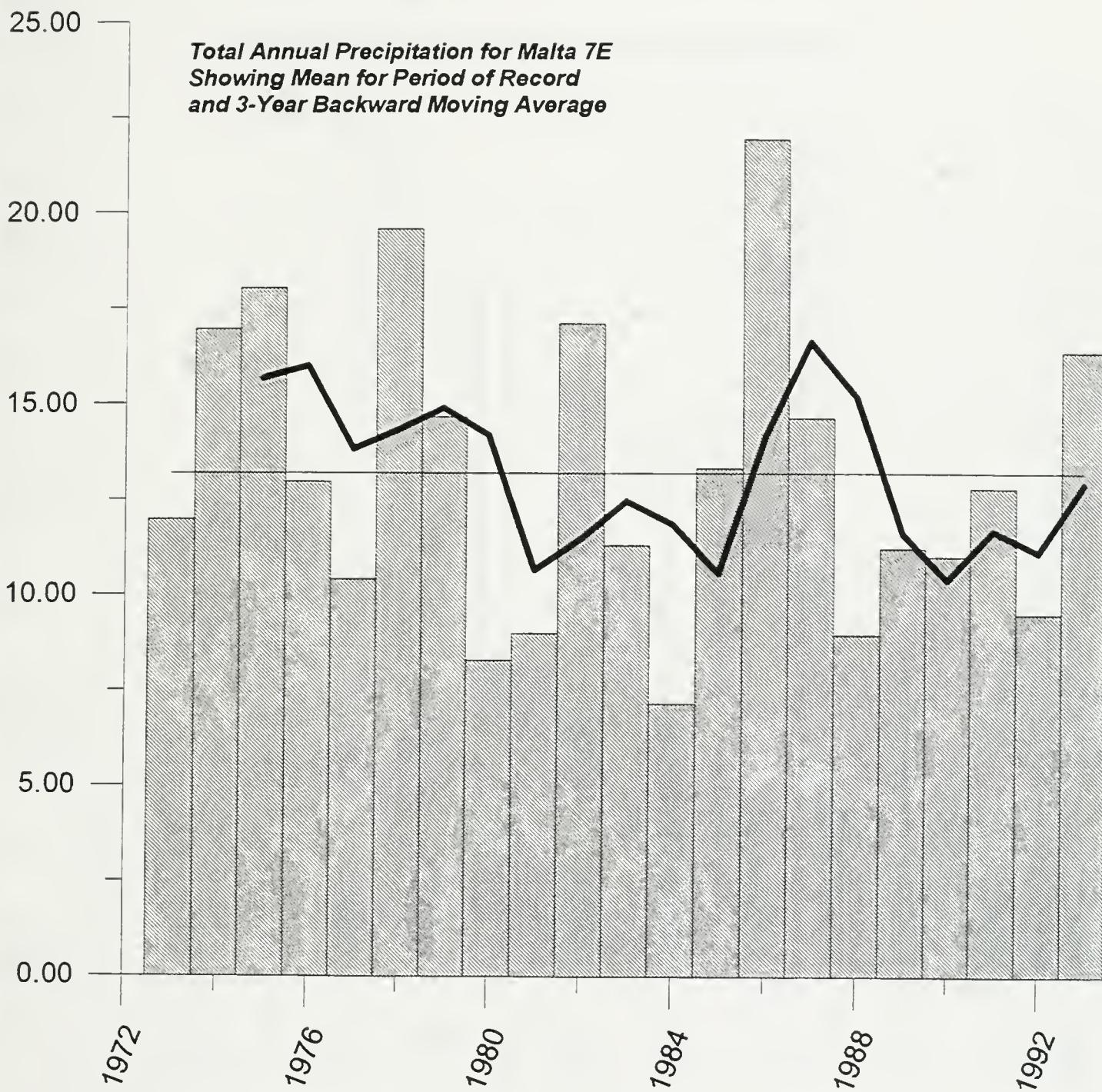
Net relief of contributing basin: 416 ft

COE Hydrogeomorphic class: FRINGE

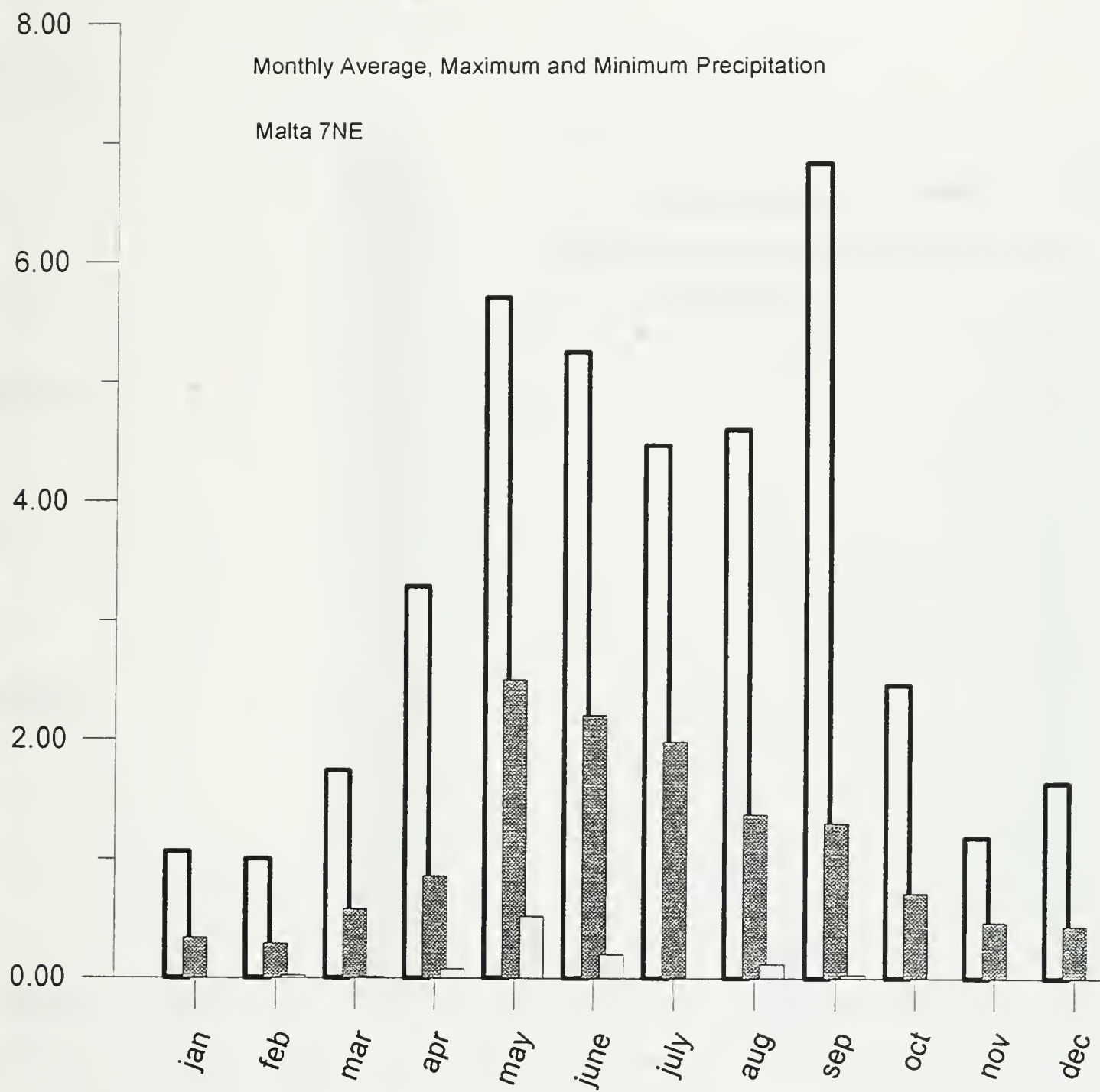
Primary surficial geologic unit 110"LAC"

Primary bedrock geologic unit 211CLGG

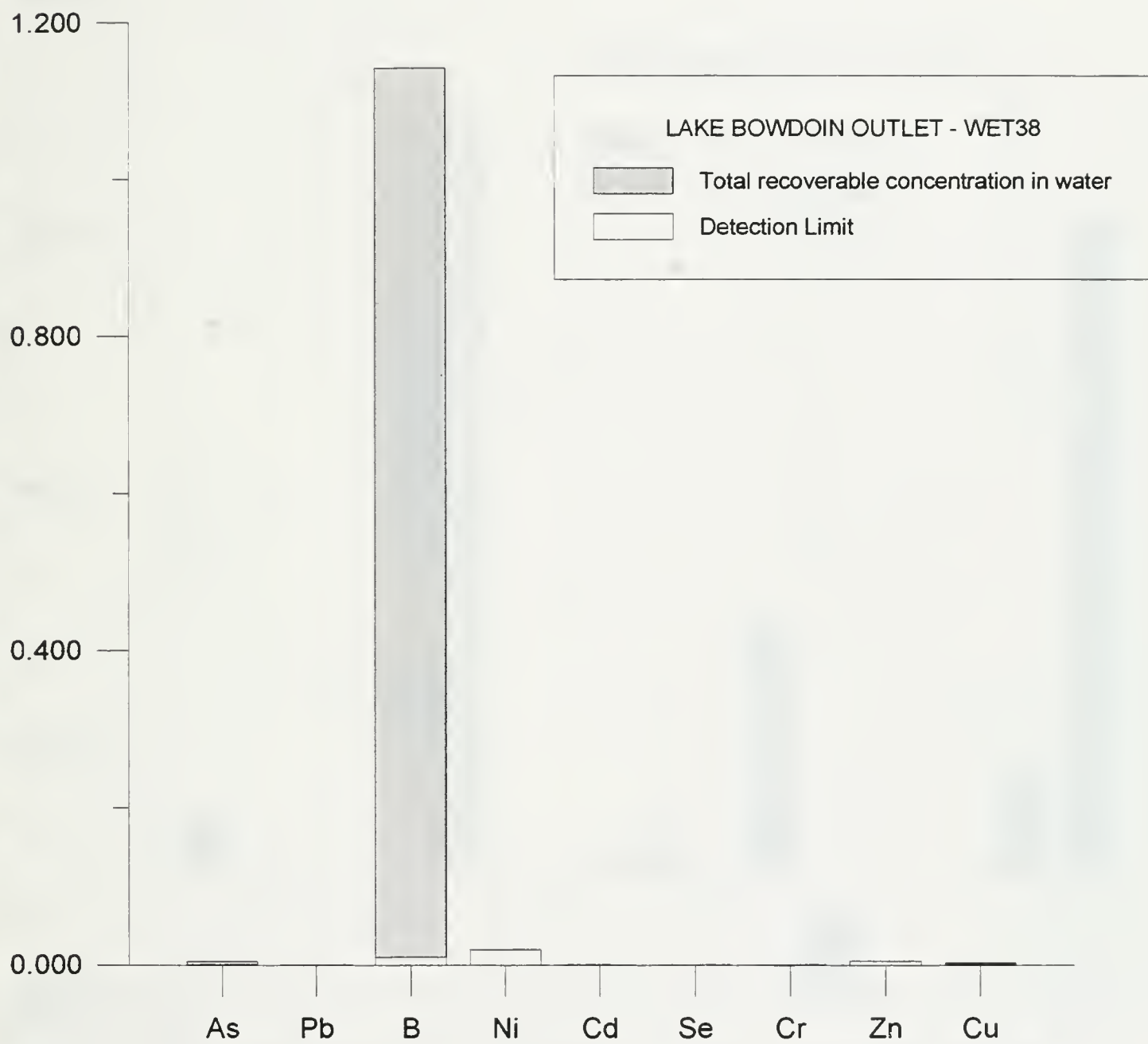
Annual Precipitation in Inches

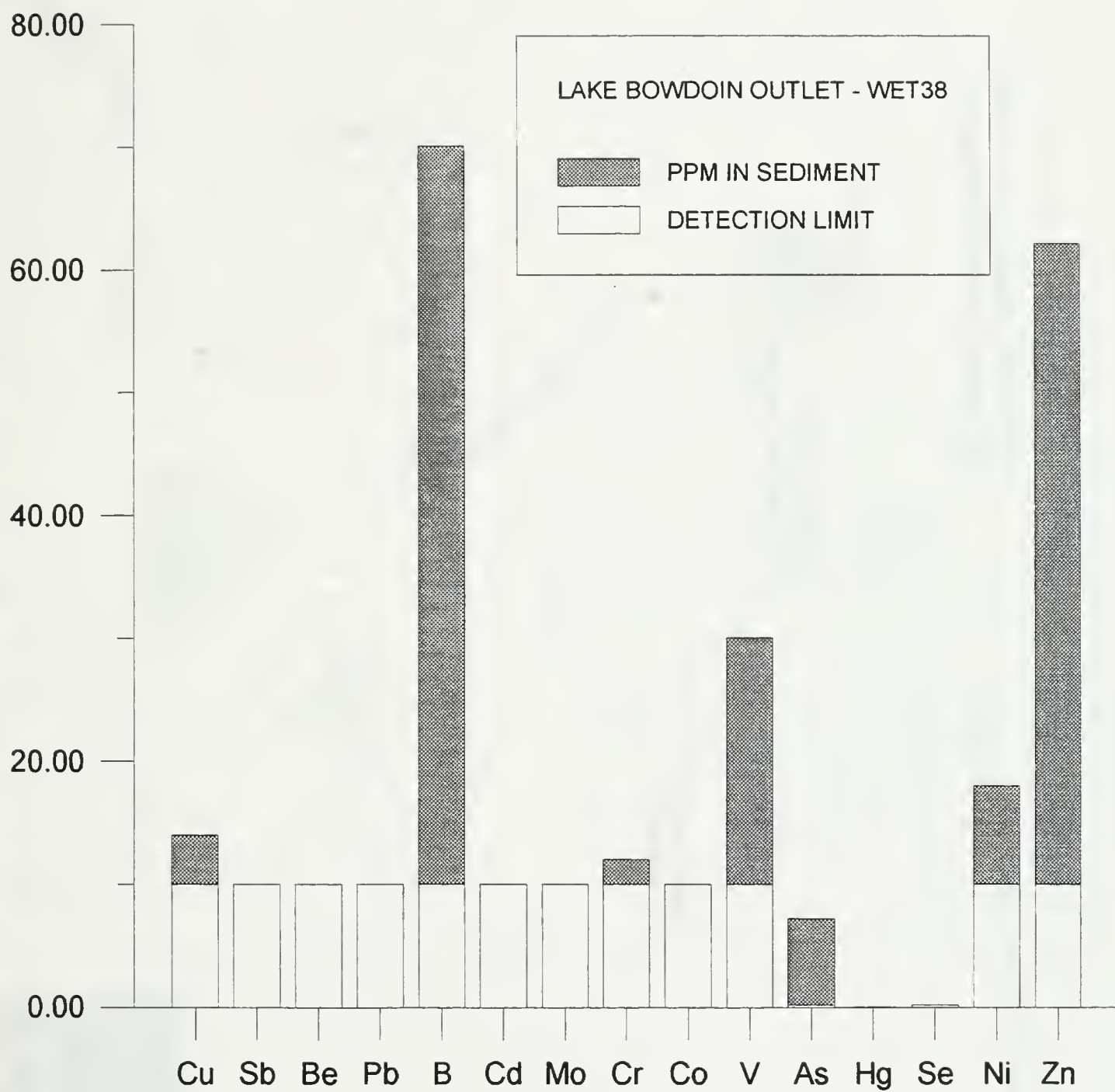


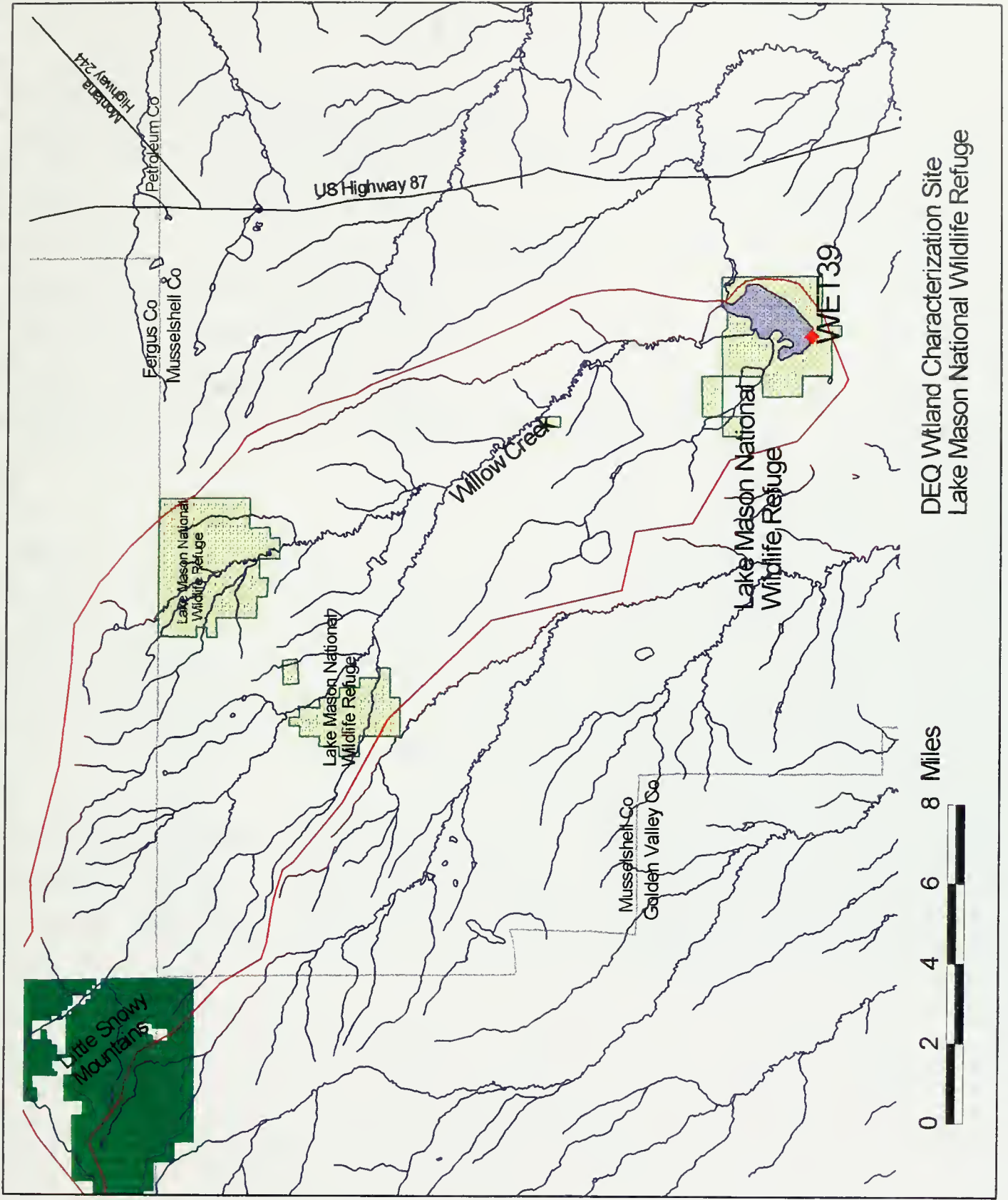
Inches Precipitation



Concentrations in Milligrams per liter







DEQ Wetland Characterization Site
Lake Mason National Wildlife Refuge

Wetland: LAKE MASON NWR

Site Code: WET39

7.5 Minute Quad: LAKE MASON

Lat: 46 30 50

Long: 108 40 25

Mean Annual Precipitation in Inches: 11.00

Mean Annual Potential Evaporation (Penman) in Inches: 41.00

'Net Precipitation' in Inches: -30.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 1220 acres

Area of contributing drainage basin: 113170 acres

Mapped elevation of wetland surface: 3606 ft

Maximum elevation within drainage basin: 5622 ft

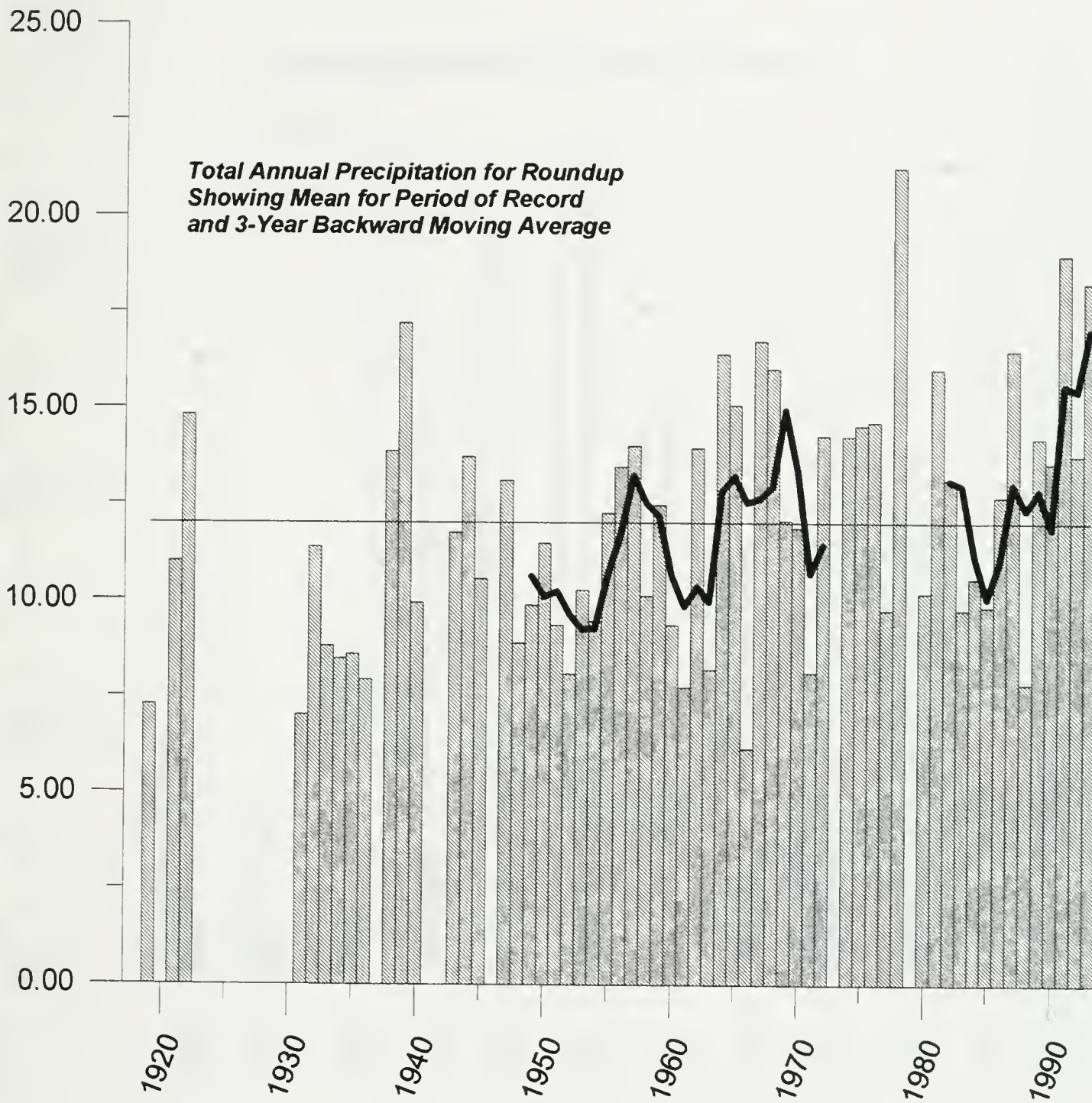
Net relief of contributing basin: 2016 ft

COE Hydrogeomorphic class: FRINGE

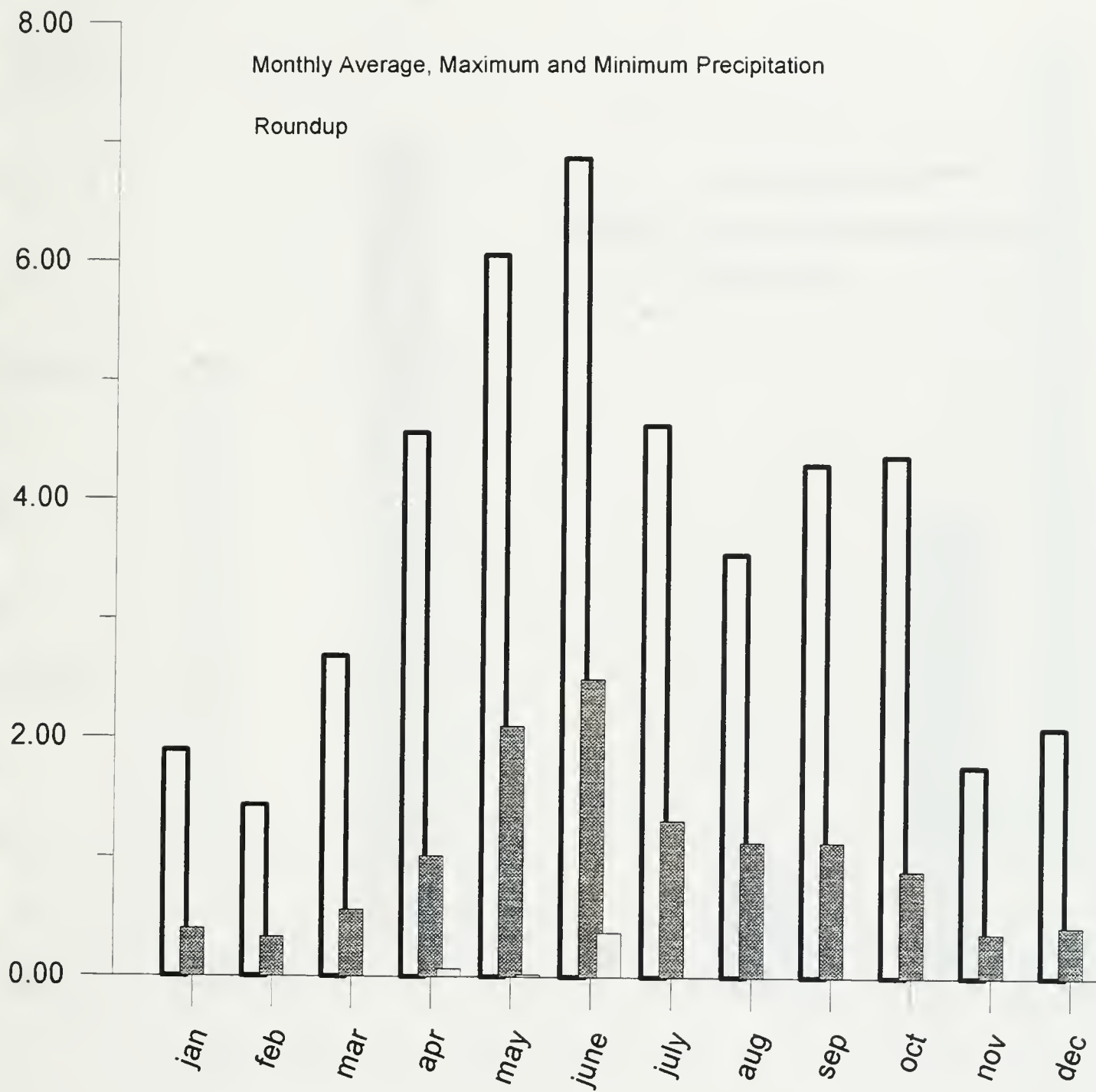
Primary surficial geologic unit 110"LAC"

Primary bedrock geologic unit 211LNCE

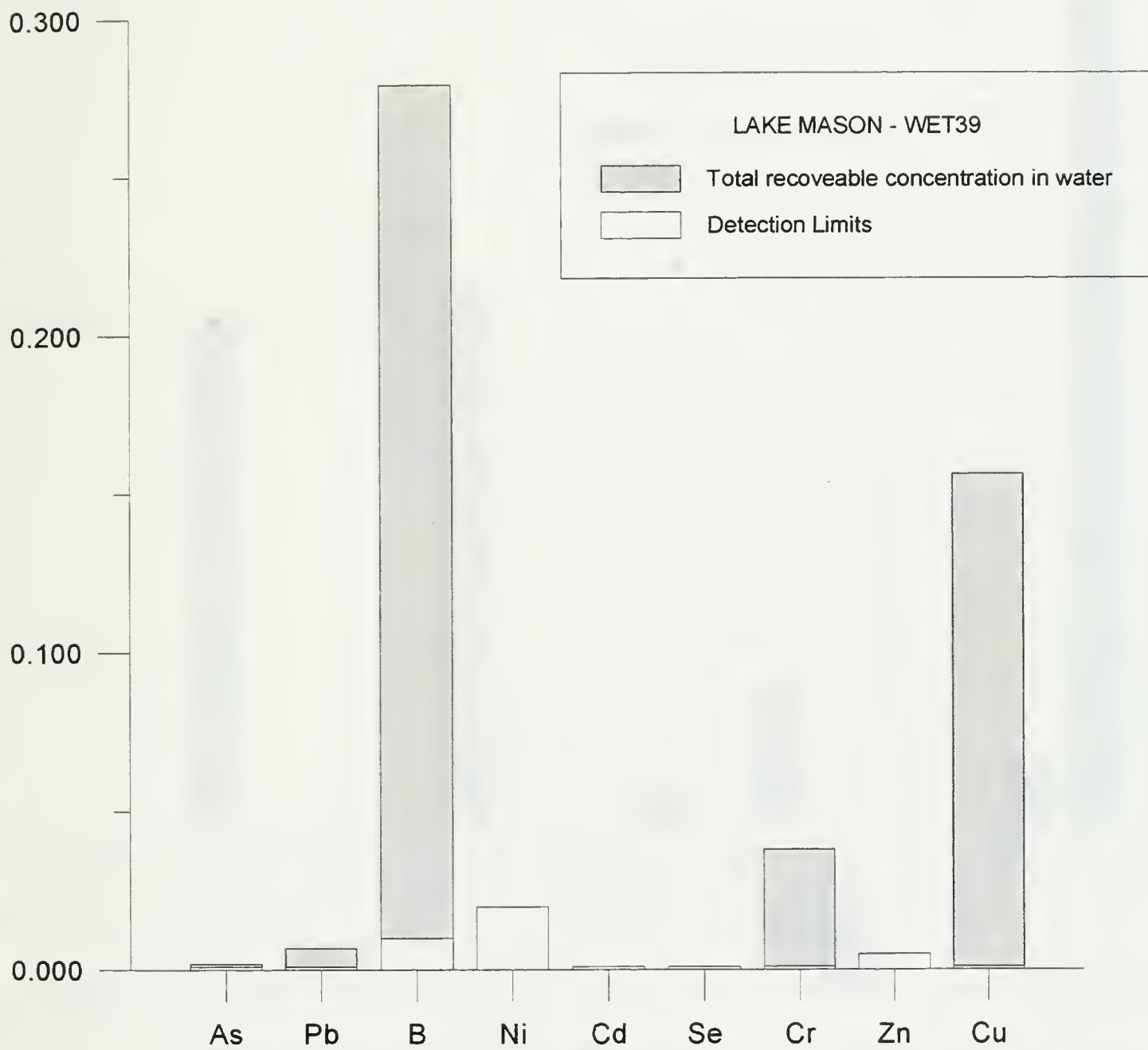
Annual Precipitation in Inches

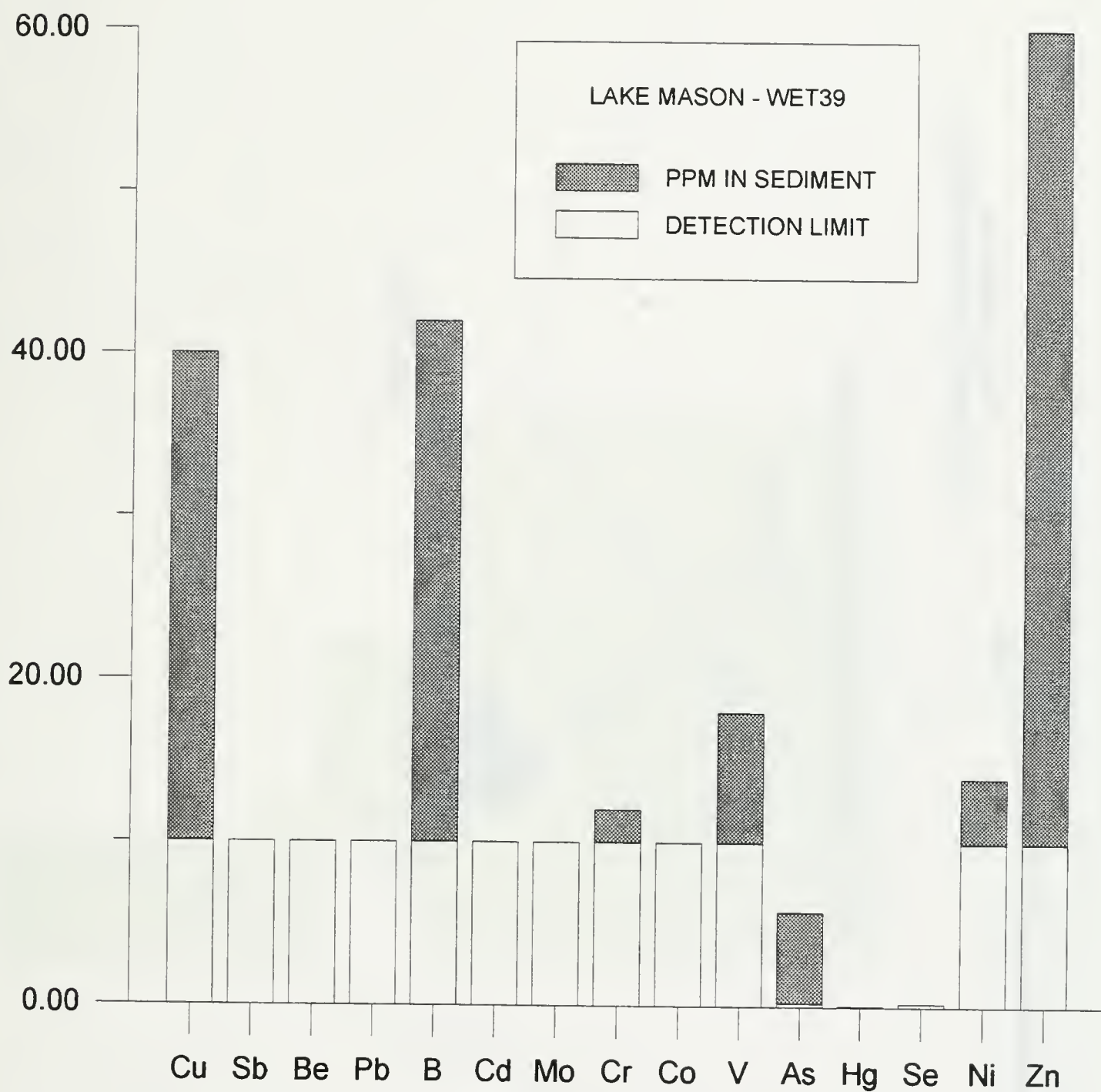


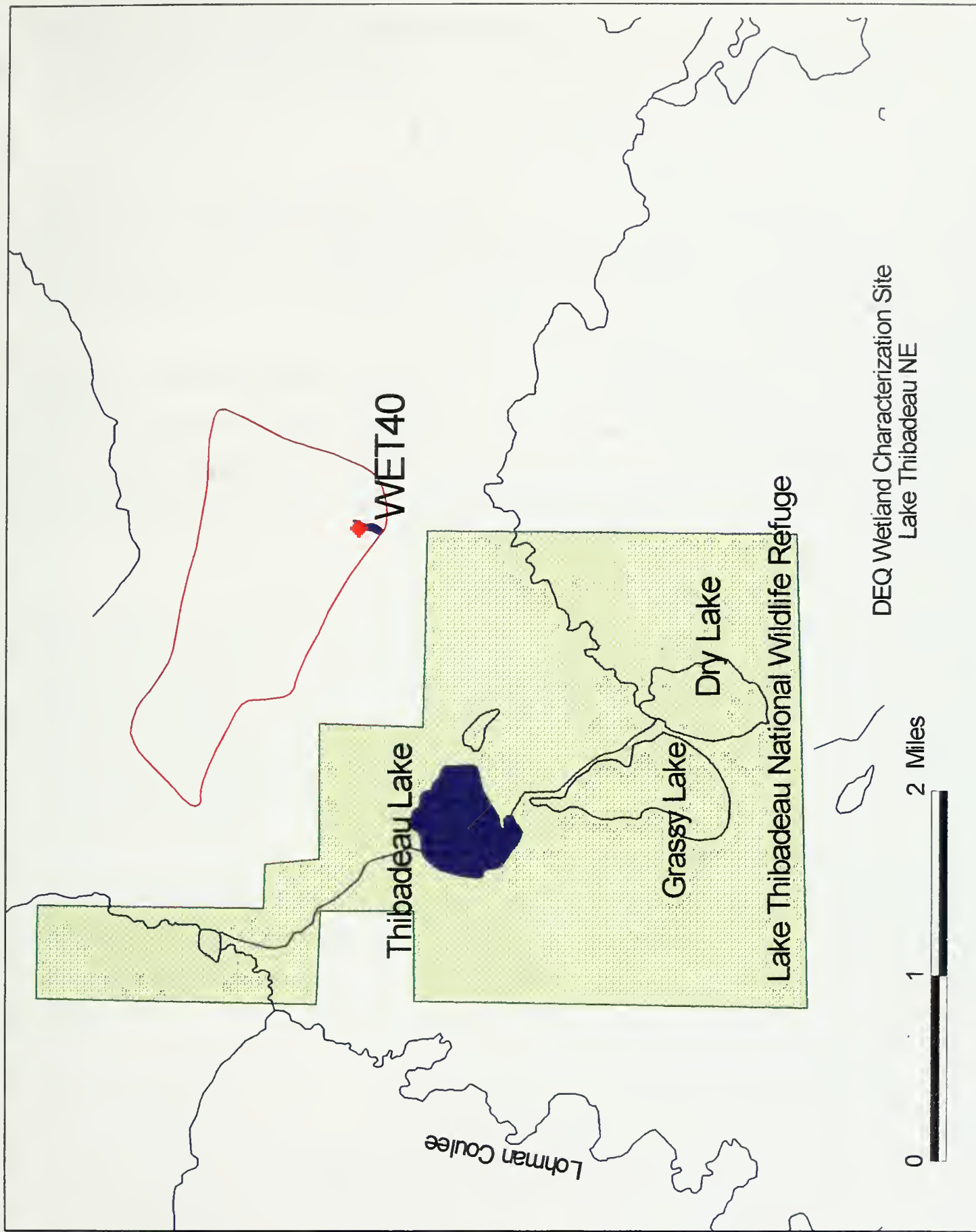
Inches Precipitation



Concentrations in Milligrams per liter







WET40

Thibadeau Lake

Grassy Lake

Dry Lake

Lake Thibadeau National Wildlife Refuge

Lohman Coulee

DEQ Wetland Characterization Site
Lake Thibadeau NE

0 1 2 Miles

Wetland: LAKE THIBADEAU NORTHEAST WETLAND

Site Code: WET40

7.5 Minute Quad: LAKE THIBADEAU

Lat: 48 46 5
Long: 109 34 10

Mean Annual Precipitation in Inches:	11.00
Mean Annual Potential Evaporation (Penman) in Inches:	37.00
'Net Precipitation' in Inches:	-26.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

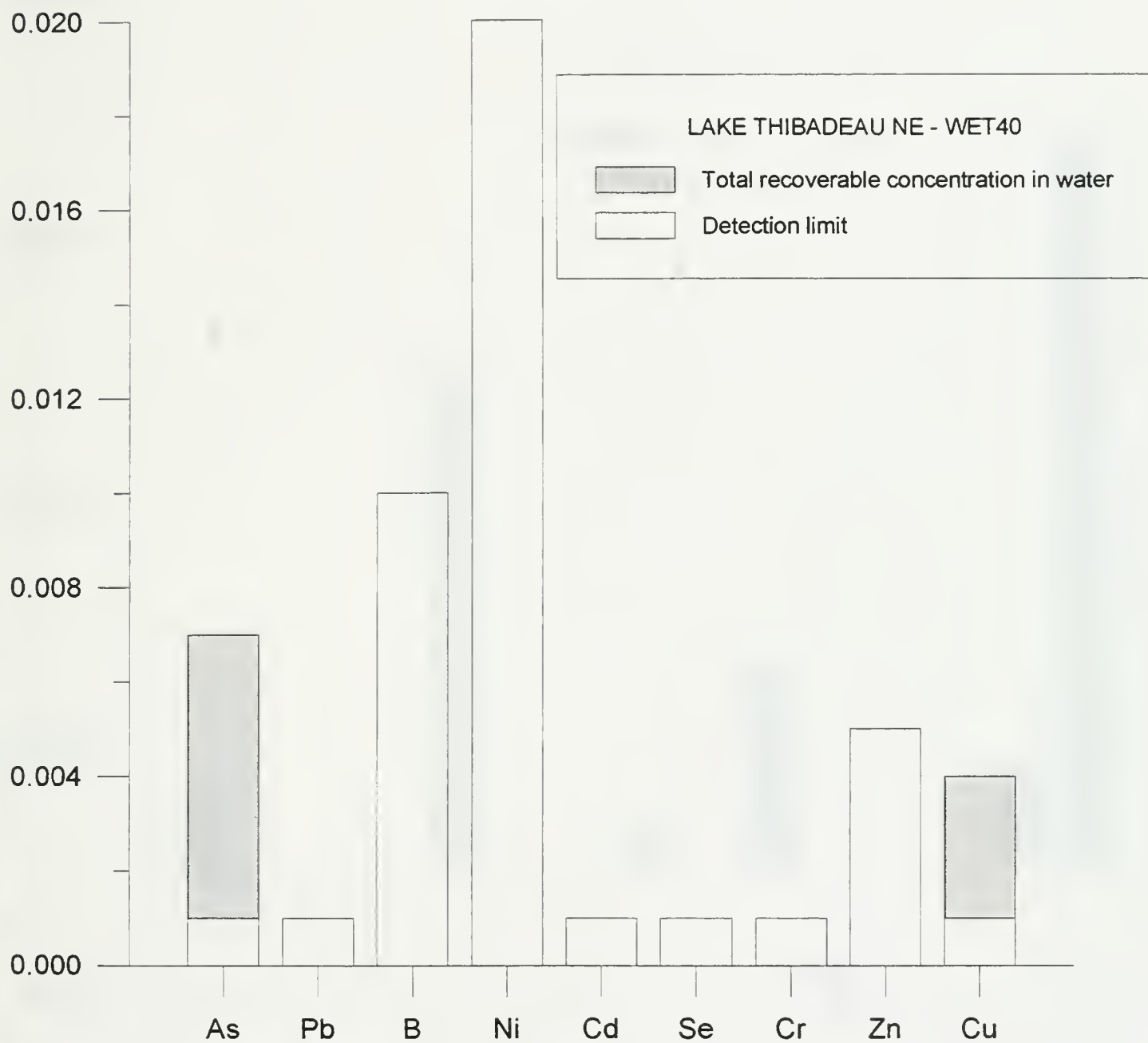
Site is artificially impounded.

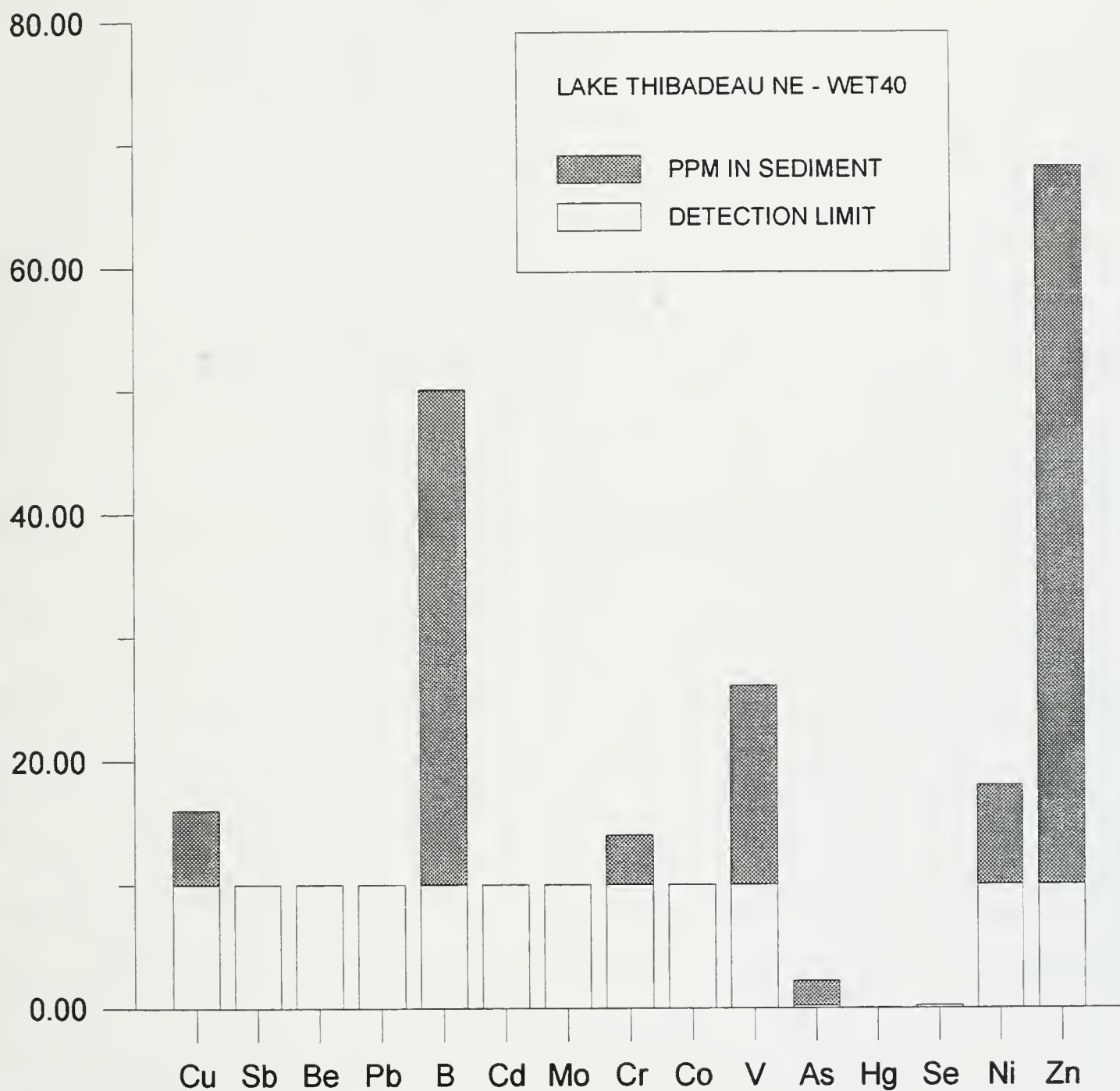
Site does not have known significant water imports.

Mapped area of wetland:	3 acres
Area of contributing drainage basin:	900 acres
Mapped elevation of wetland surface:	2722 ft
Maximum elevation within drainage basin:	2787 ft
Net relief of contributing basin:	65 ft

COE Hydrogeomorphic class:	DEPRESSIONAL
Primary surficial geologic unit	112DRFT
Primary bedrock geologic unit	211BRPW

Concentrations in Milligrams per liter





5

551, 41

N 11 GGC

1995

Appendix A, Part 2

Appendix A

Data Summaries and Maps of the DEQ Wetland Characterization Sites

Part 2, Sites WET41 - WET80

2
1H. 122
M. G. C.
1991
Chry. A. 1/10/91

Appendix A

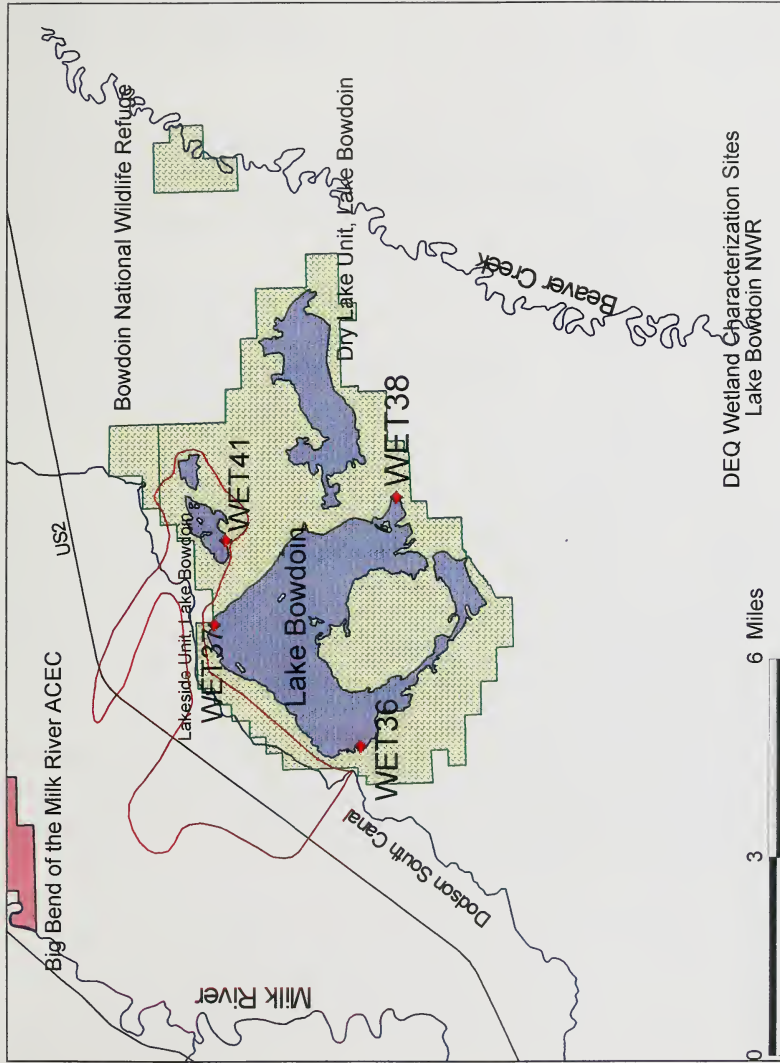
Data Summaries and Maps of the
DEQ Wetland Characterization Sites

Part 2, Sites WET41 - WET80

MONTANA STATE LIBRARY



3 0864 0014 8943 7



Wetland: LAKESIDE WETLAND

Site Code: WET41

7.5 Minute Quad: LAKE BOWDOIN

Lat: 48 25 25
Long: 107 39 20

Mean Annual Precipitation in Inches:	11.00
Mean Annual Potential Evaporation (Penman) in Inches:	39.00
'Net Precipitation' in Inches:	-28.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

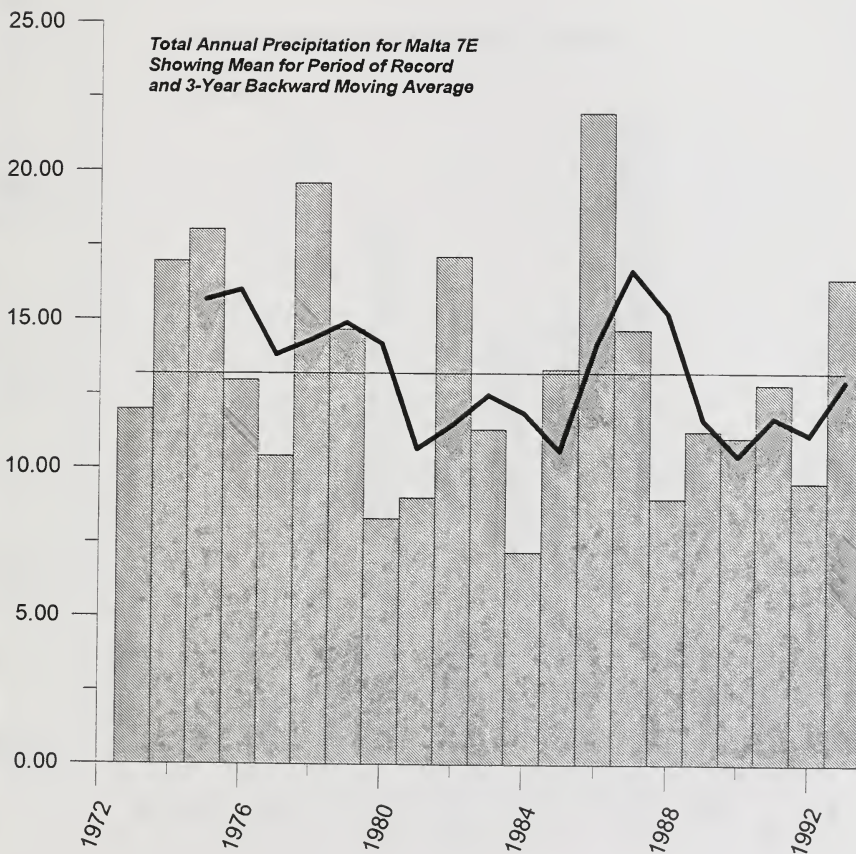
Site is not known to be artificially impounded.

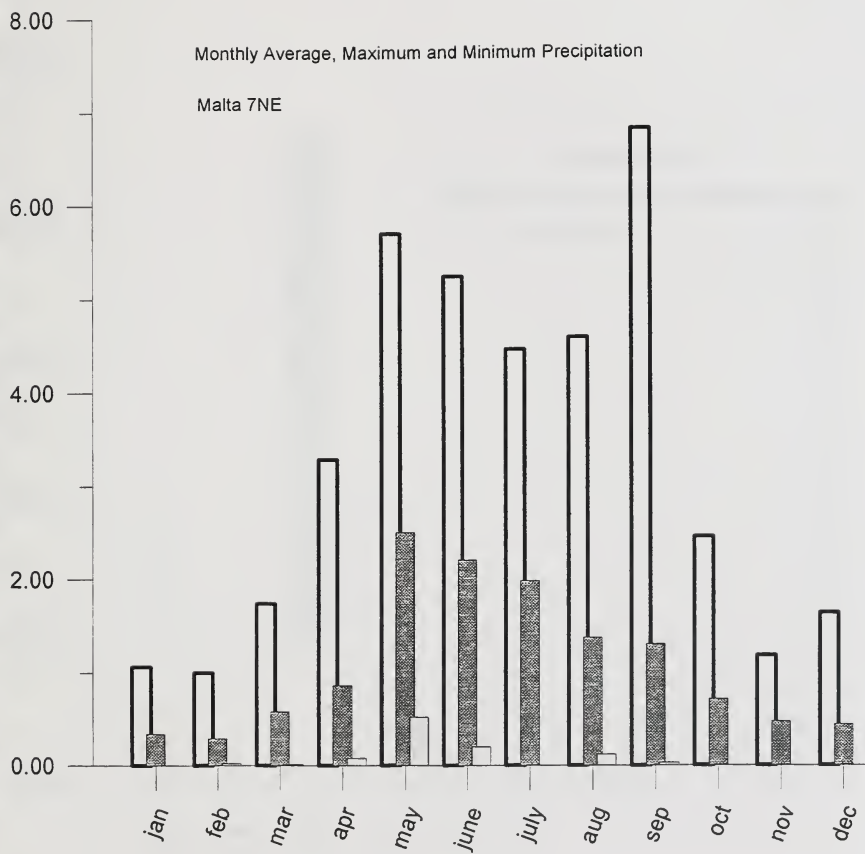
Site has significant water imports.

Mapped area of wetland:	194 acres
Area of contributing drainage basin:	5460 acres
Mapped elevation of wetland surface:	2226 ft
Maximum elevation within drainage basin:	2286 ft
Net relief of contributing basin:	60 ft

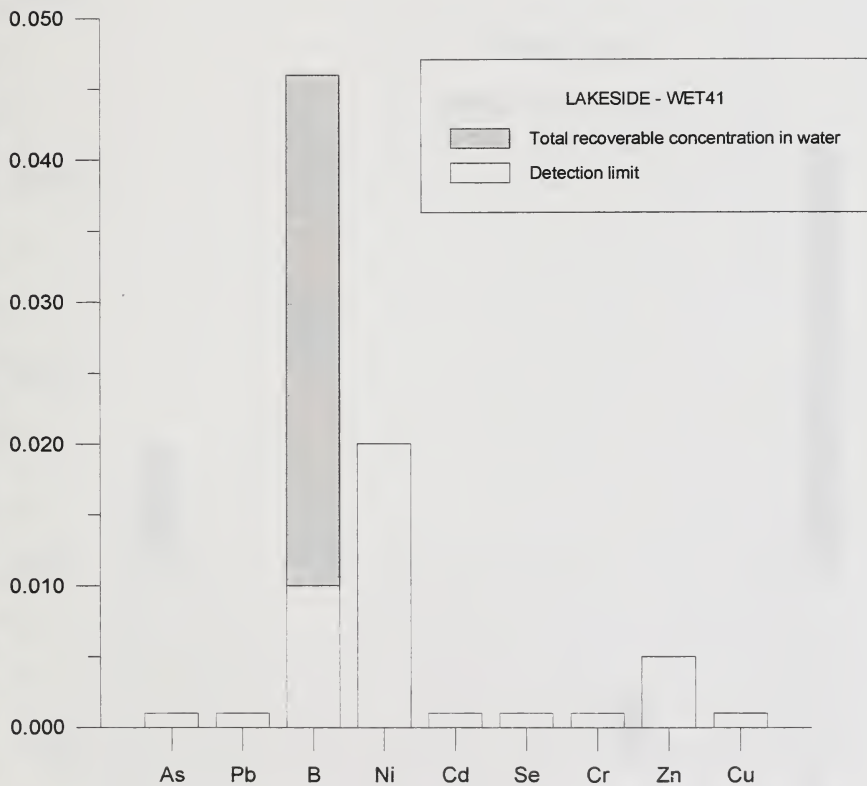
COE Hydrogeomorphic class:	FRINGE
Primary surficial geologic unit	110"LAC"
Primary bedrock geologic unit	211CLGG

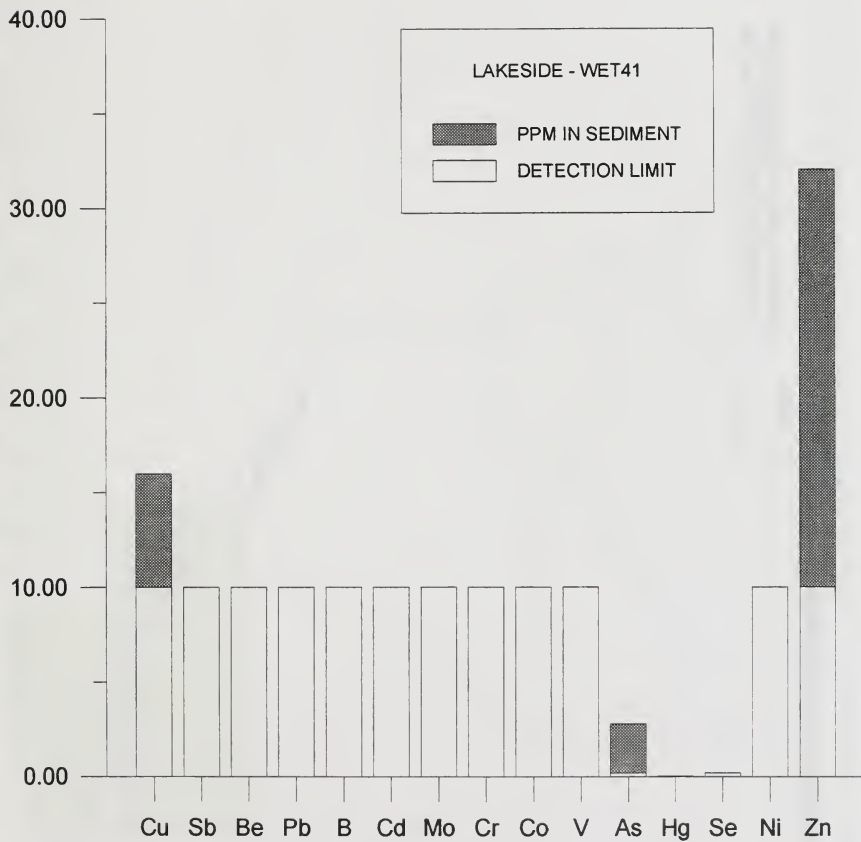
Annual Precipitation in Inches

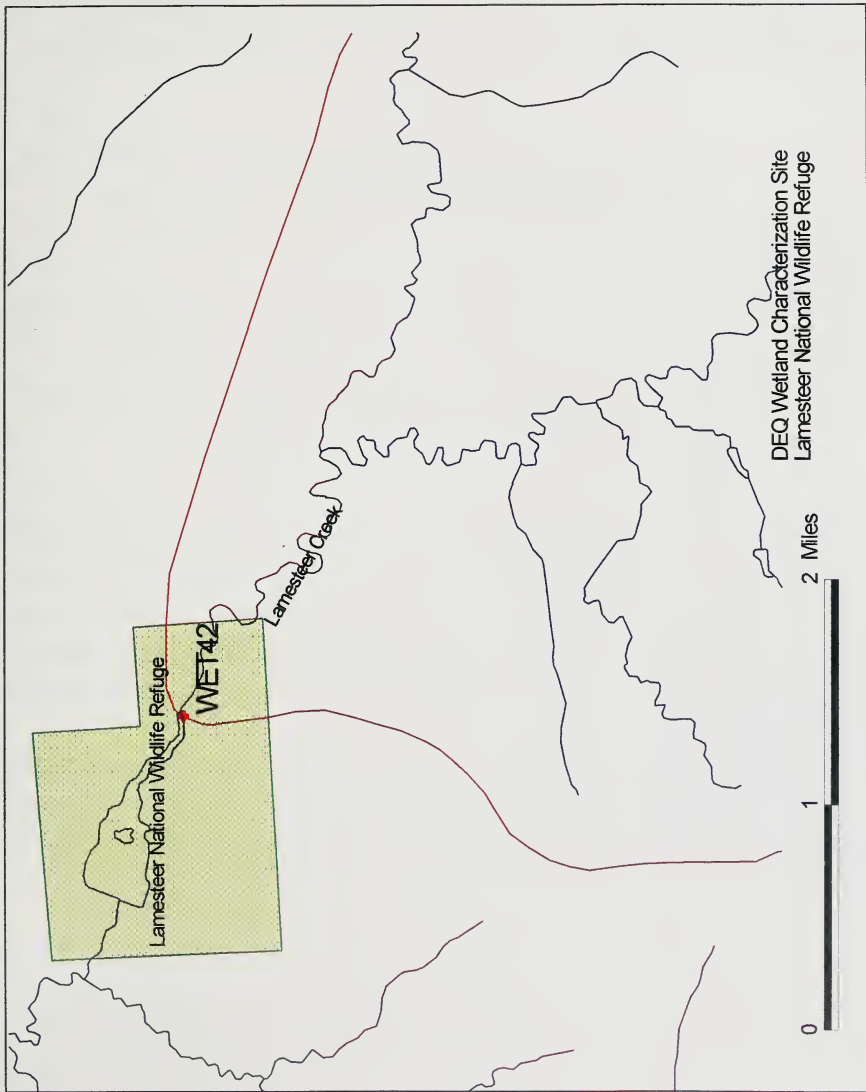




Concentrations in Milligrams per liter







Wetland: LAMESTEER NWR

Site Code: WET42

7.5 Minute Quad: RED TOP BUTTE

Lat: 46 47 30

Long: 104 8 40

Mean Annual Precipitation in Inches: 15.00

Mean Annual Potential Evaporation (Penman) in Inches: 38.00

'Net Precipitation' in Inches: -23.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 60 acres

Area of contributing drainage basin: 17000 acres

Mapped elevation of wetland surface: 2883 ft

Maximum elevation within drainage basin: 3247 ft

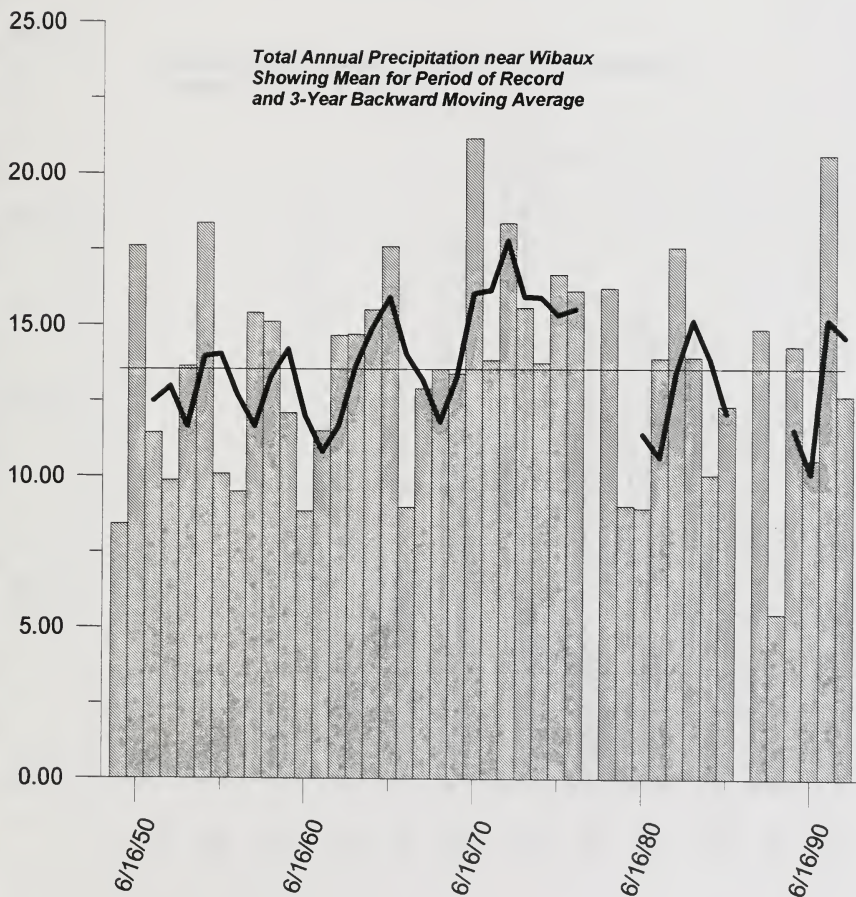
Net relief of contributing basin: 364 ft

COE Hydrogeomorphic class: FRINGE

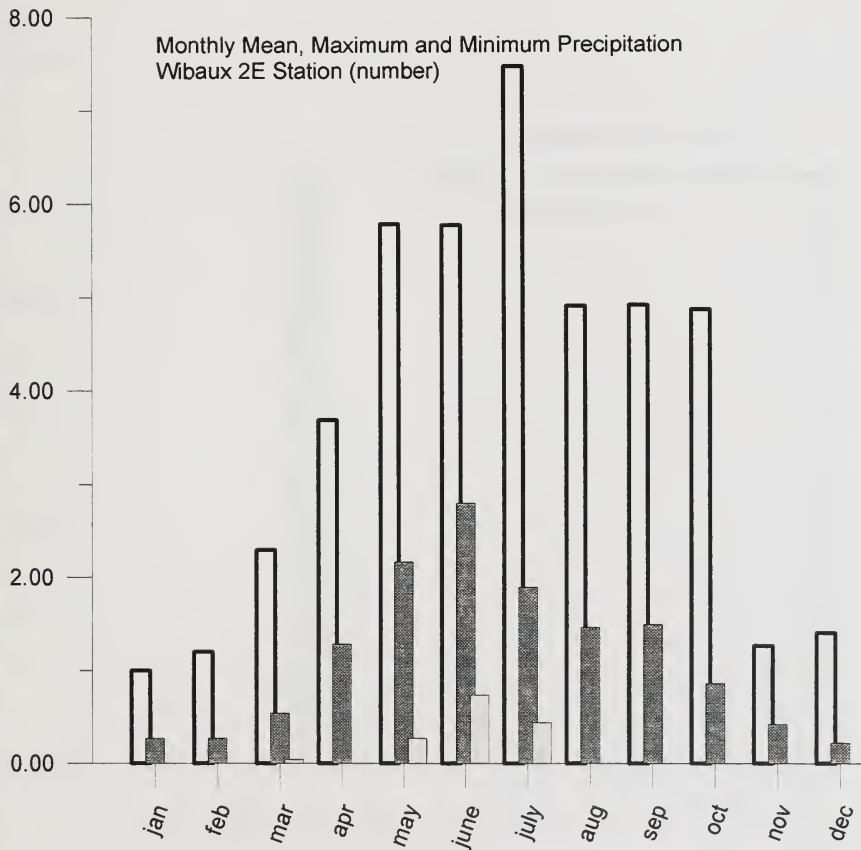
Primary surficial geologic unit 111"LAC"

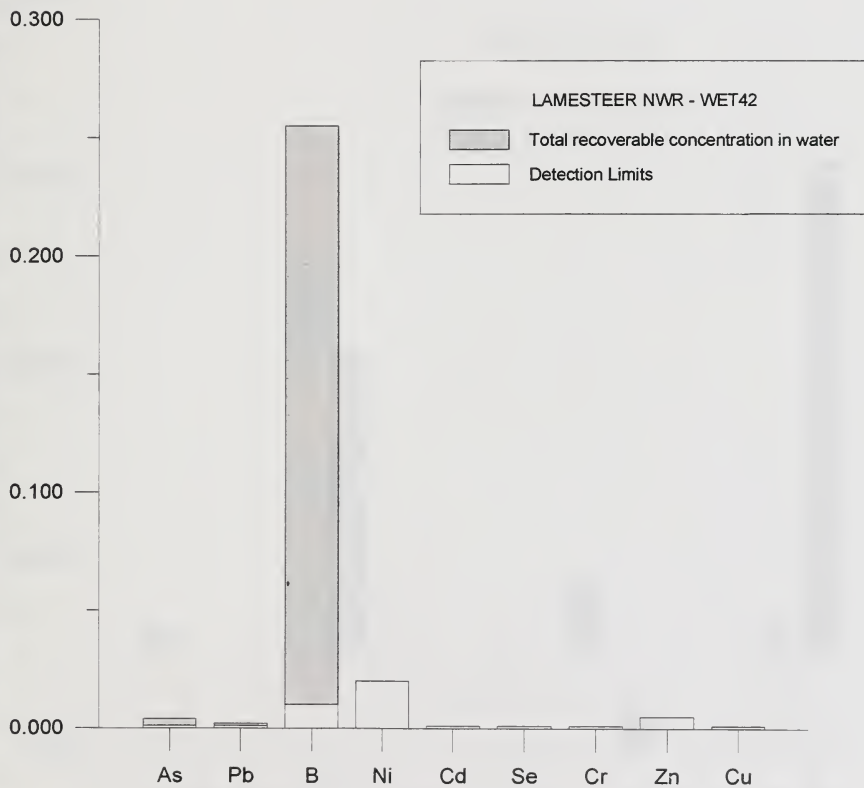
Primary bedrock geologic unit 125TGRV

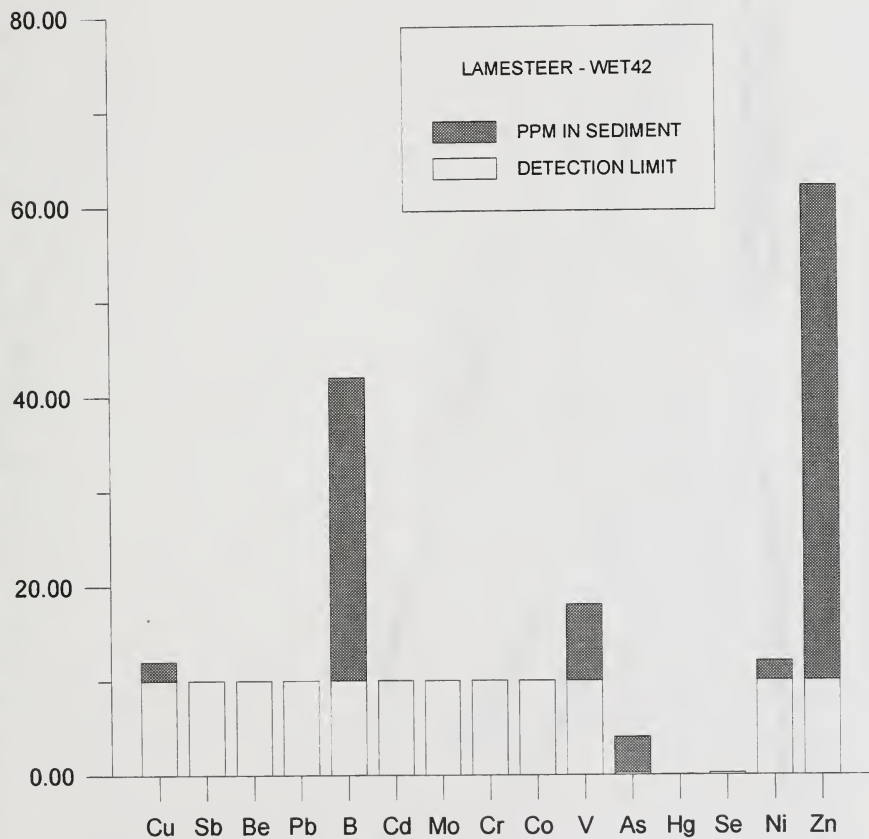
Annual Precipitation in Inches

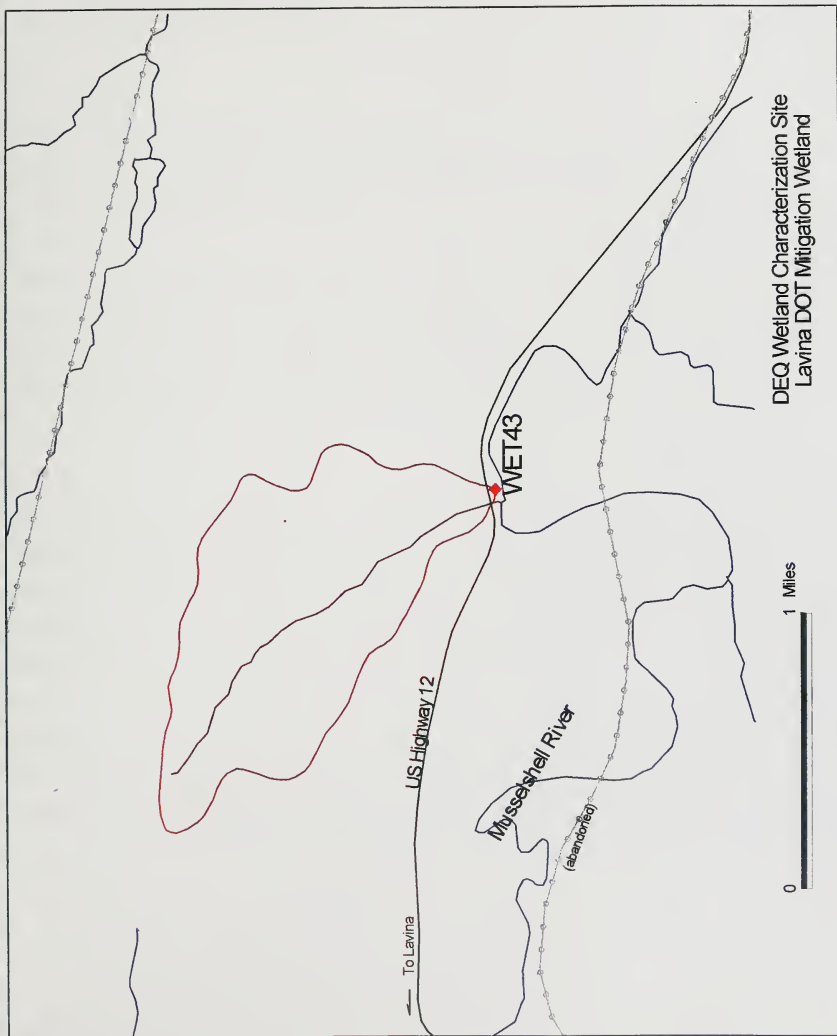


Monthly Mean, Maximum and Minimum Precipitation
Wibaux 2E Station (number)









Wetland: LAVINA DOT MITIGATION WETLAND

Site Code: WET43

7.5 Minute Quad: RYGATE EAST

Lat: 46 18 55

Long: 109 8 25

Mean Annual Precipitation in Inches: 13.00

Mean Annual Potential Evaporation (Penman) in Inches: 42.00

'Net Precipitation' in Inches: -29.00

Site has a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 5 acres

Area of contributing drainage basin: 560 acres

Mapped elevation of wetland surface: 3560 ft

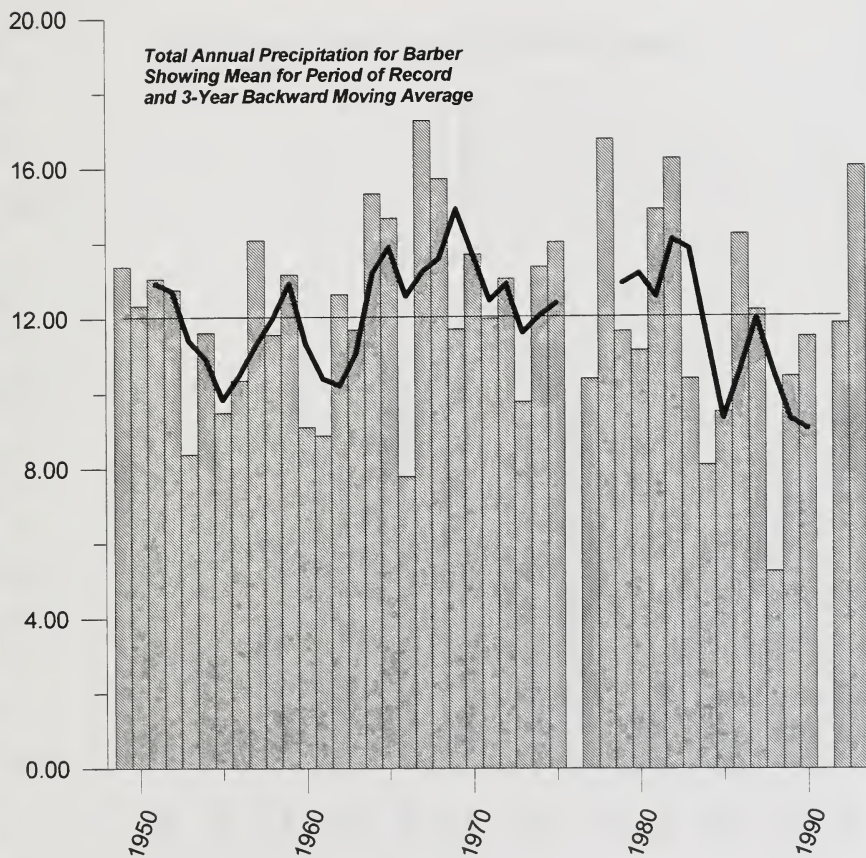
Maximum elevation within drainage basin: 3858 ft

Net relief of contributing basin: 298 ft

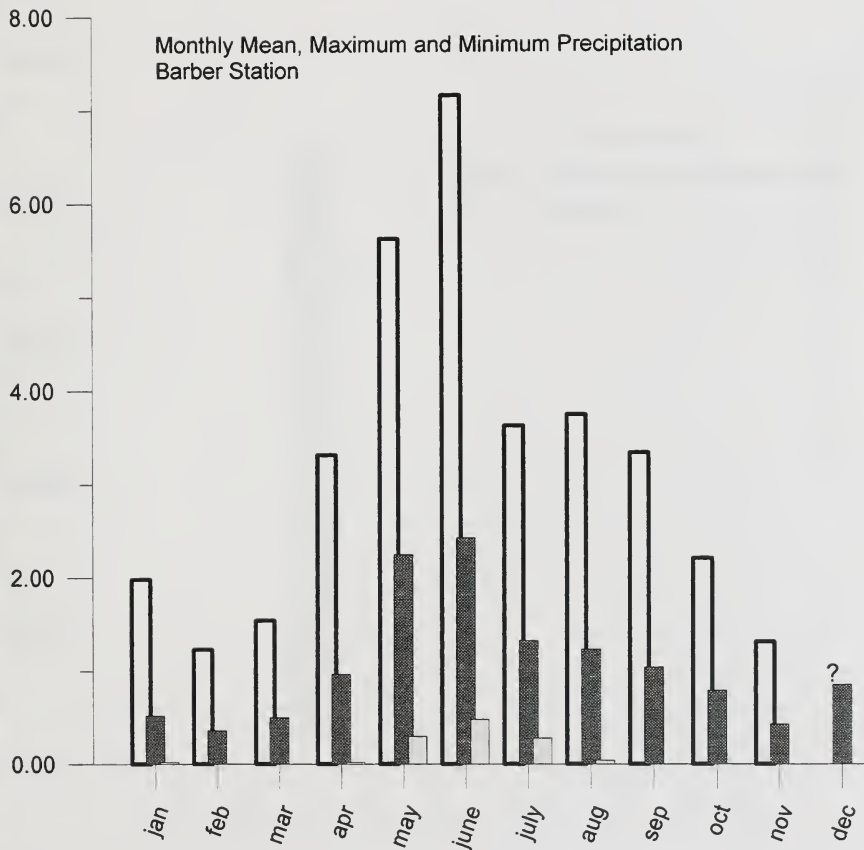
COE Hydrogeomorphic class: DEPRESSIONAL

Primary surficial geologic unit 110ALVM

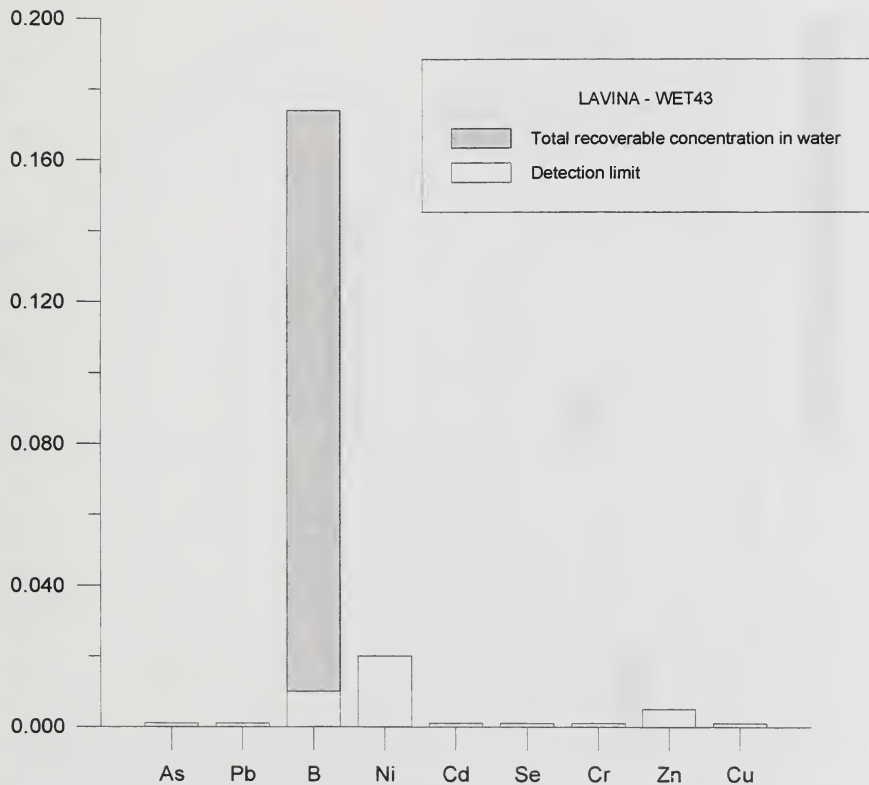
Primary bedrock geologic unit 211JDRV

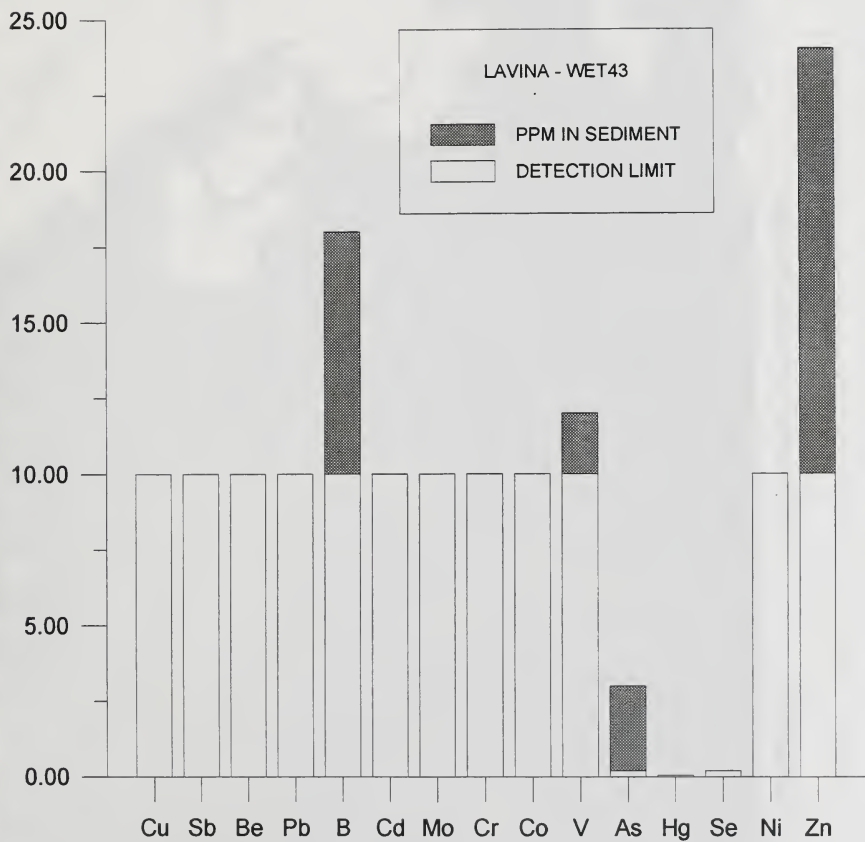


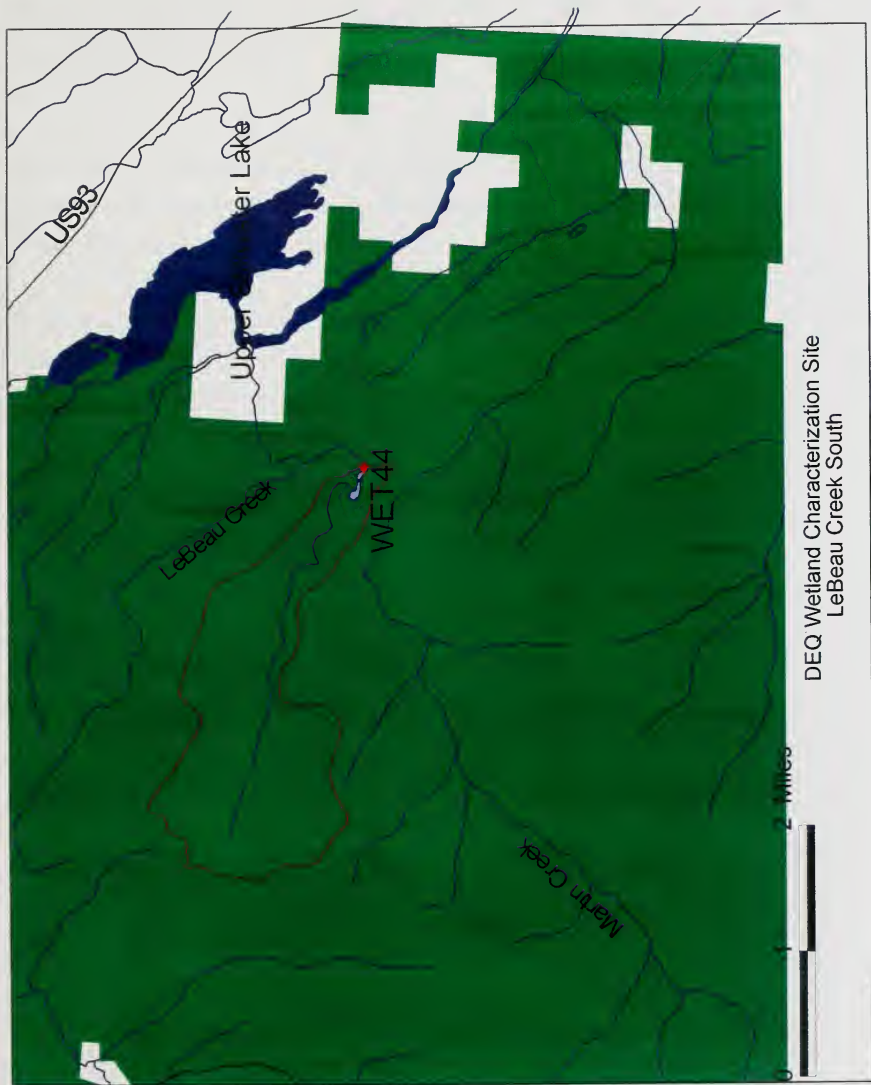
Monthly Mean, Maximum and Minimum Precipitation
Barber Station



Concentrations in Milligrams per liter







Wetland: LEBEAU CREEK SOUTH WETLAND

Site Code: WET44

7.5 Minute Quad: RADNOR

Lat: 48 34 5
Long: 114 40 0

Mean Annual Precipitation in Inches: 25.00

Mean Annual Potential Evaporation (Penman) in Inches: 30.00

'Net Precipitation' in Inches: -5.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 7 acres

Area of contributing drainage basin: 1840 acres

Mapped elevation of wetland surface: 3550 ft

Maximum elevation within drainage basin: 5635 ft

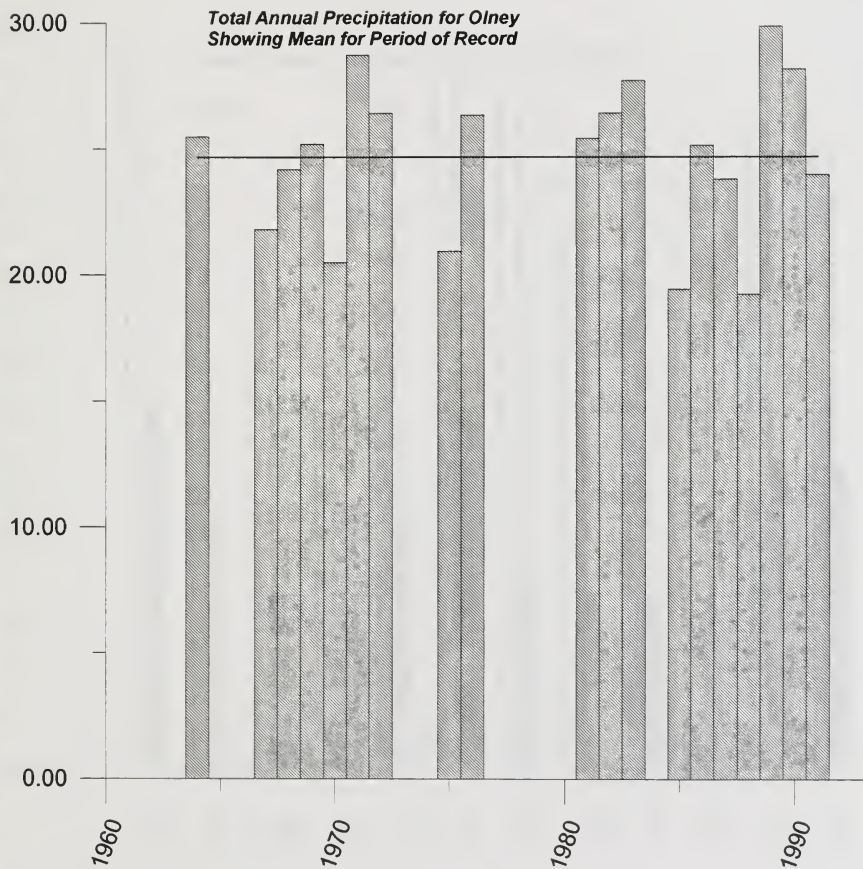
Net relief of contributing basin: 2085 ft

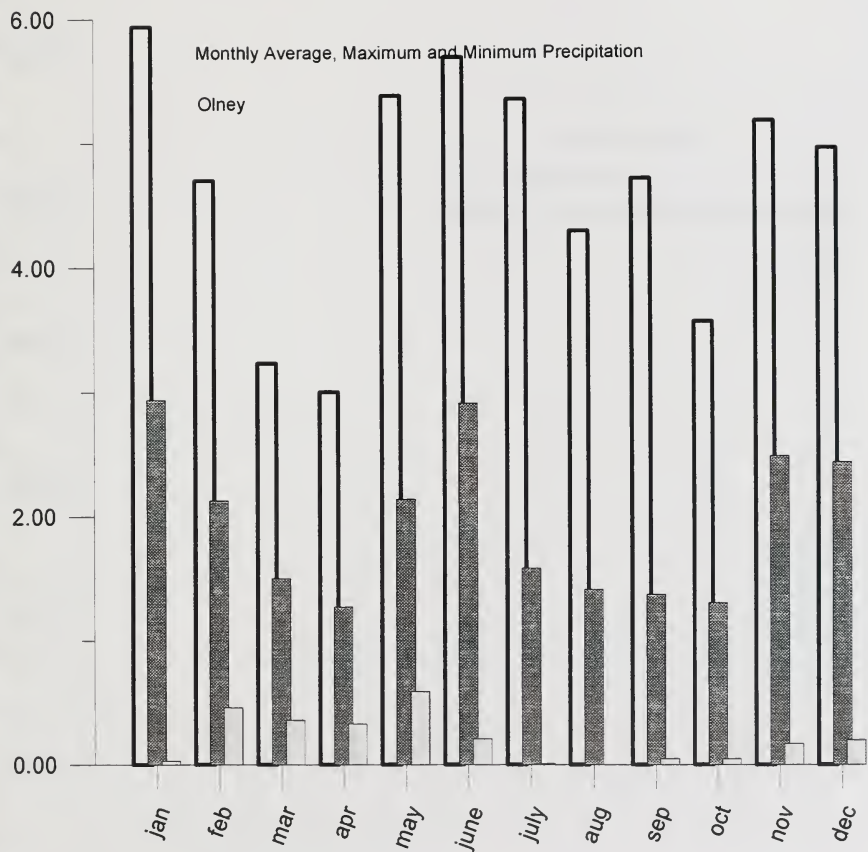
COE Hydrogeomorphic class: RIVERINE

Primary surficial geologic unit 112DRFT

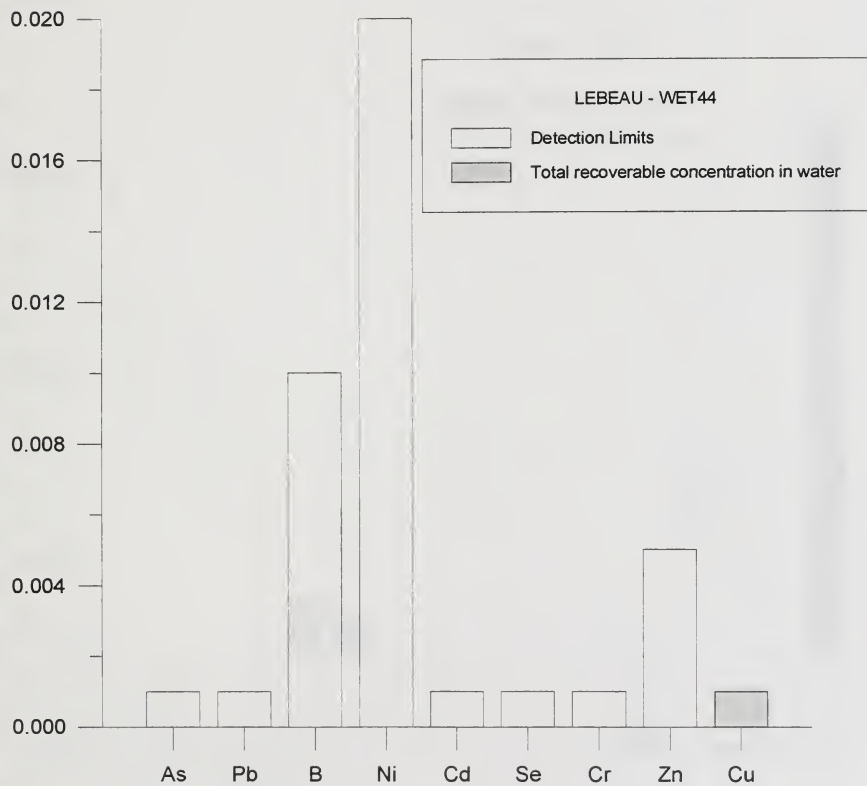
Primary bedrock geologic unit 400BELT

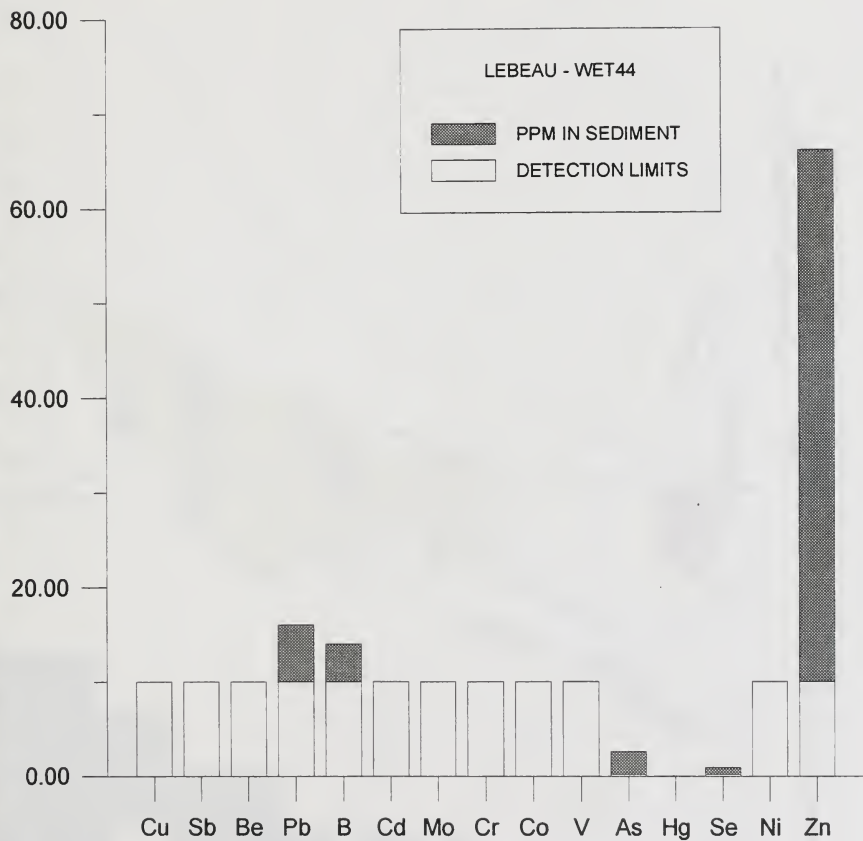
Annual Precipitation in Inches

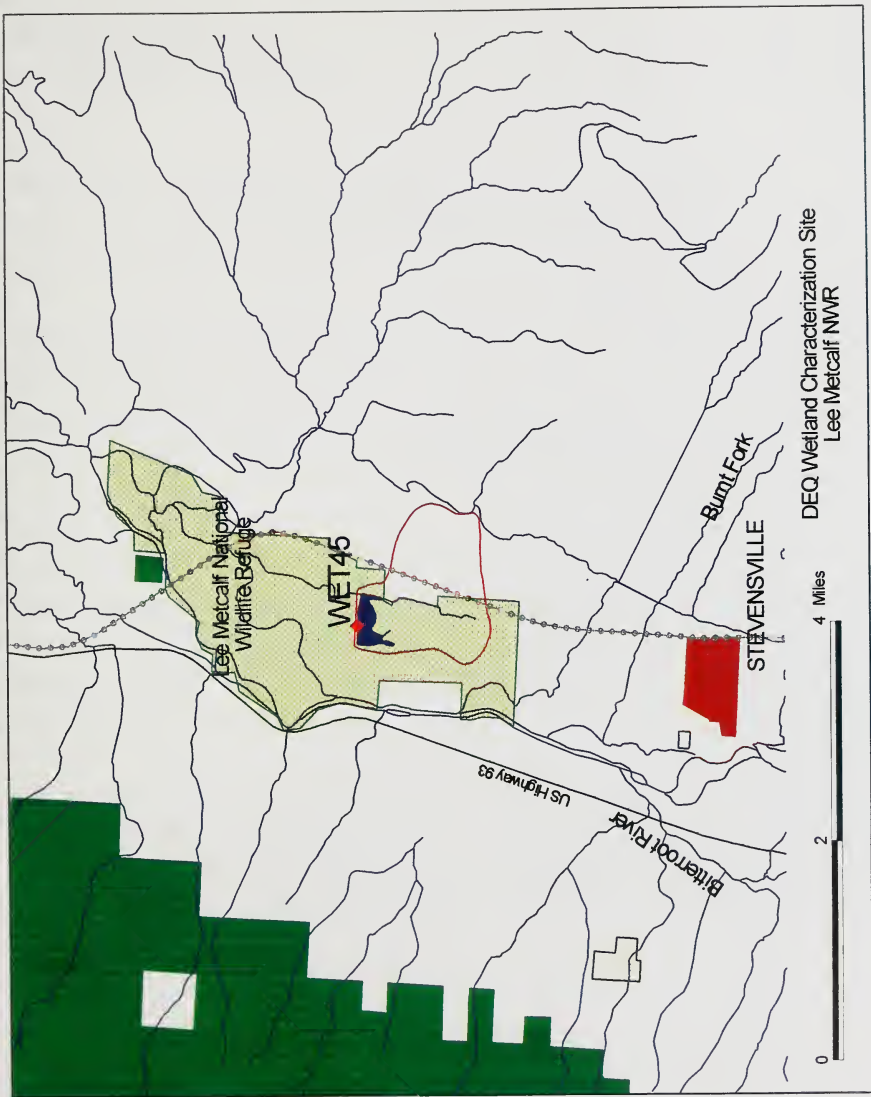




Concentrations in Milligrams per liter







Wetland: LEE METCALF NWR

Site Code: WET45

7.5 Minute Quad: STEVENSVILLE

Lat: 46 33 20

Long: 114 4 58

Mean Annual Precipitation in Inches: 11.00

Mean Annual Potential Evaporation (Penman) in Inches: 35.00

'Net Precipitation' in Inches: -24.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 50 acres

Area of contributing drainage basin: 810 acres

Mapped elevation of wetland surface: 3255 ft

Maximum elevation within drainage basin: 3365 ft

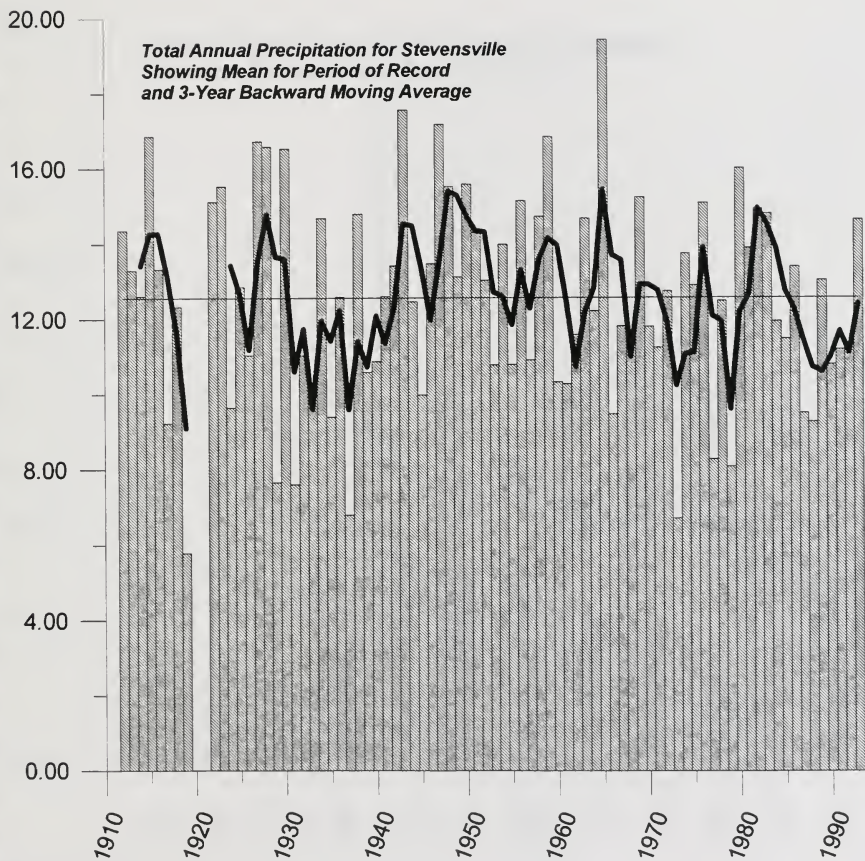
Net relief of contributing basin: 110 ft

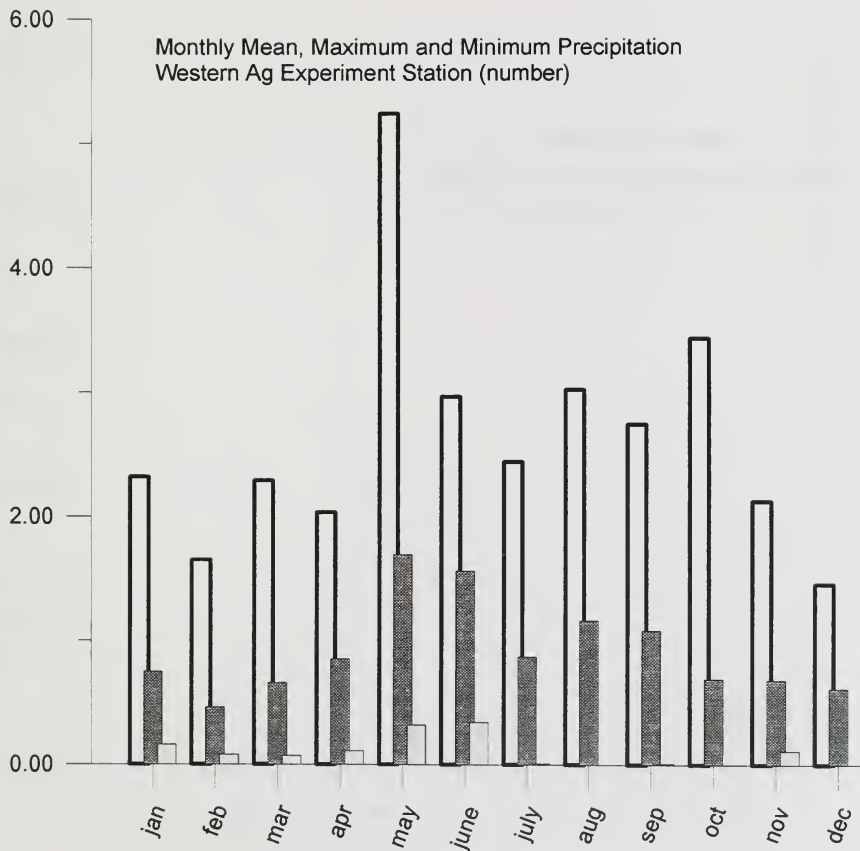
COE Hydrogeomorphic class: DEPRESSIONAL

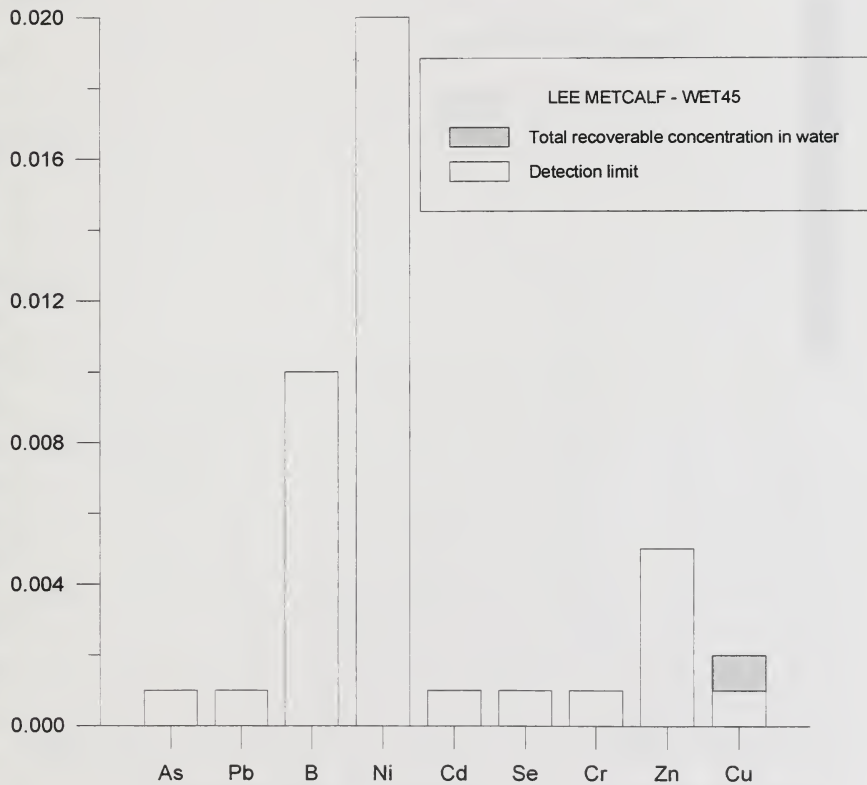
Primary surficial geologic unit 111ALVM

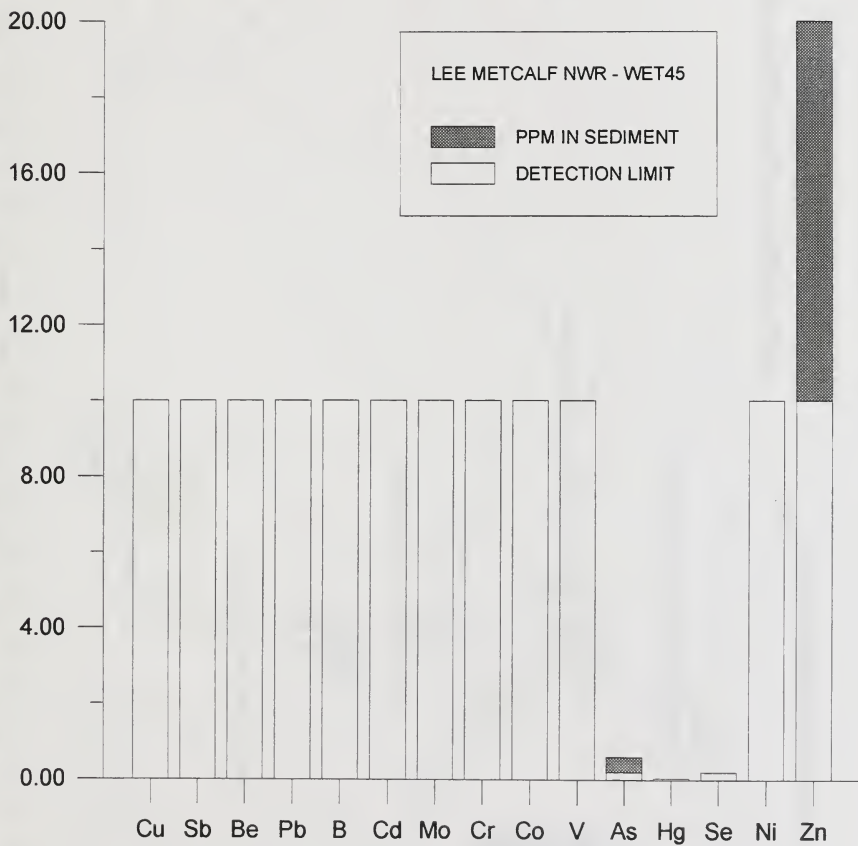
Primary bedrock geologic unit 120SDMS

Annual Precipitation in Inches









Canada

Elmer Waterfowl Production Area

Danbrook Waterfowl Production Area

Willshaw
Flats

Dunk Waterfowl Production Area

Brown Waterfowl Production Area

WE 146

Long Lake Waterfowl Production Area

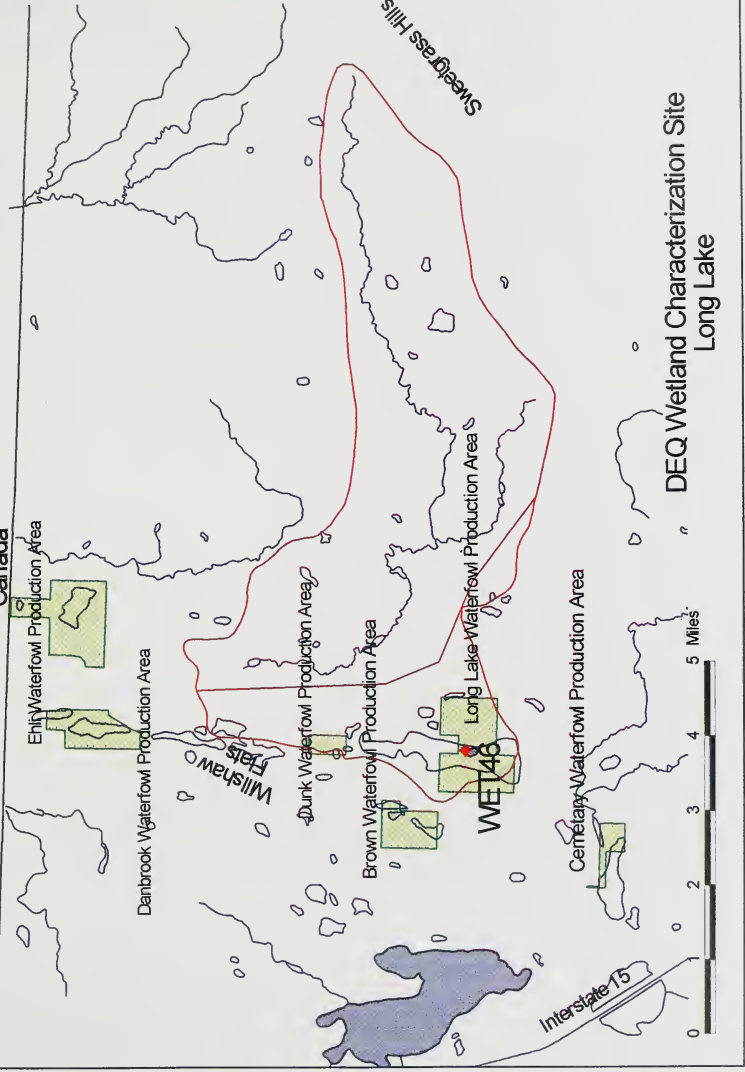
Cemetary Waterfowl Production Area

Interstate 15

DEQ Wetland Characterization Site
Long Lake

0 1 2 3 4 5 Miles

Sweetgrass Hills



Wetland: LONG LAKE WPA

Site Code: WET46

7.5 Minute Quad: WILLSHAW FLATS

Lat: 48 54 30

Long: 111 49 20

Mean Annual Precipitation in Inches: 11.00

Mean Annual Potential Evaporation (Penman) in Inches: 37.00

'Net Precipitation' in Inches: -26.00

Site has a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 10 acres

Area of contributing drainage basin: 3200 acres

Mapped elevation of wetland surface: 3315 ft

Maximum elevation within drainage basin: 4404 ft

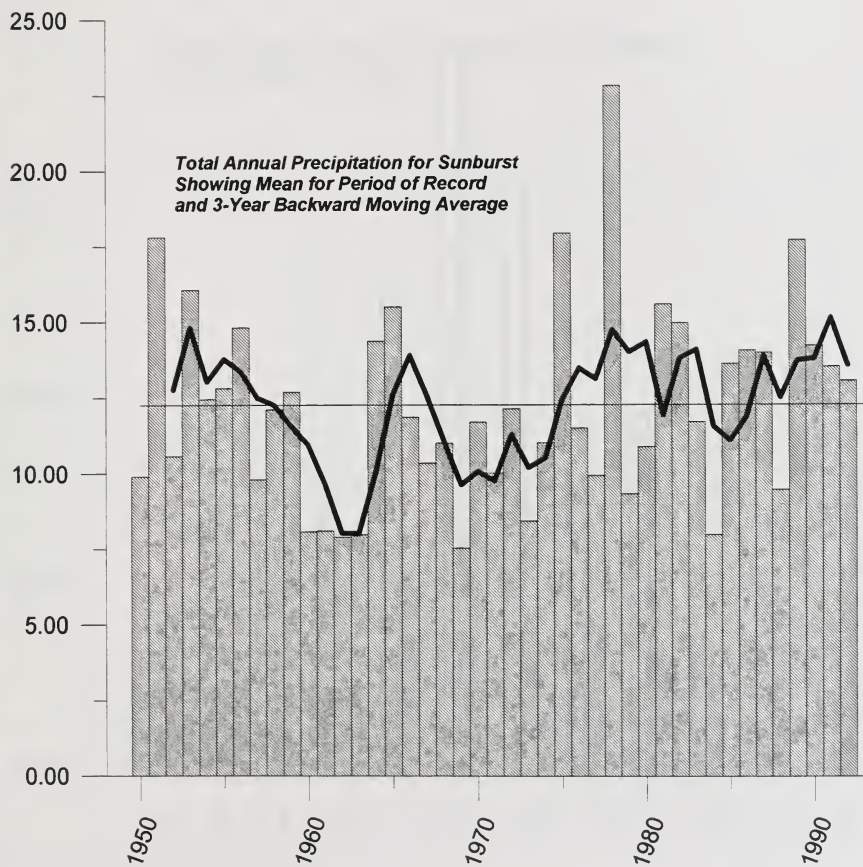
Net relief of contributing basin: 1089 ft

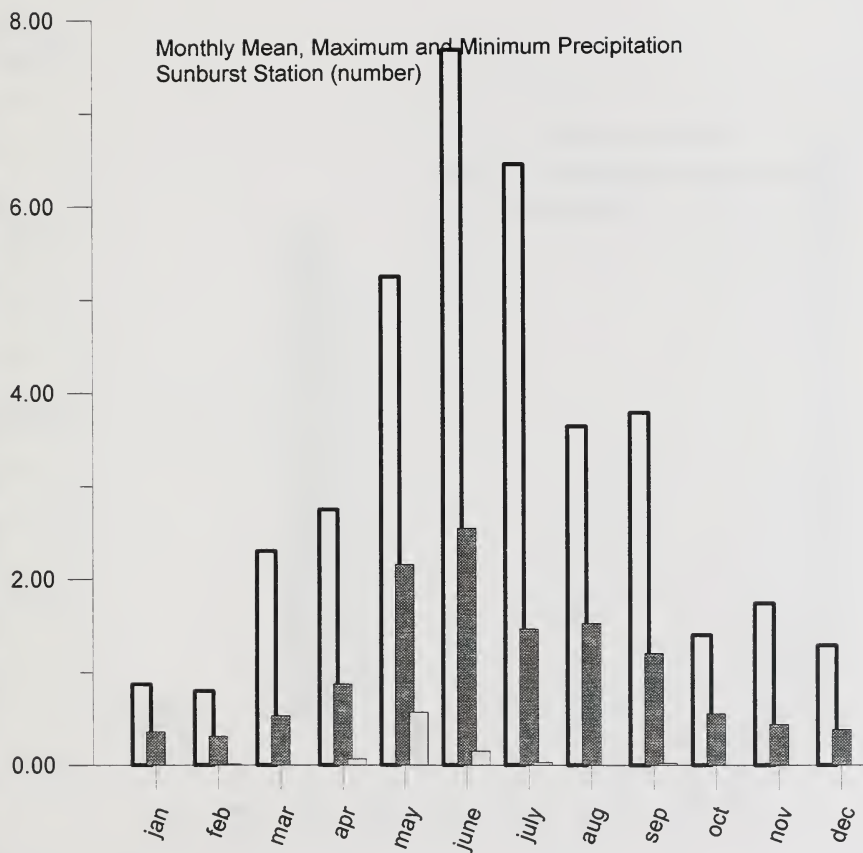
COE Hydrogeomorphic class: DEPRESSIONAL

Primary surficial geologic unit 112TILL

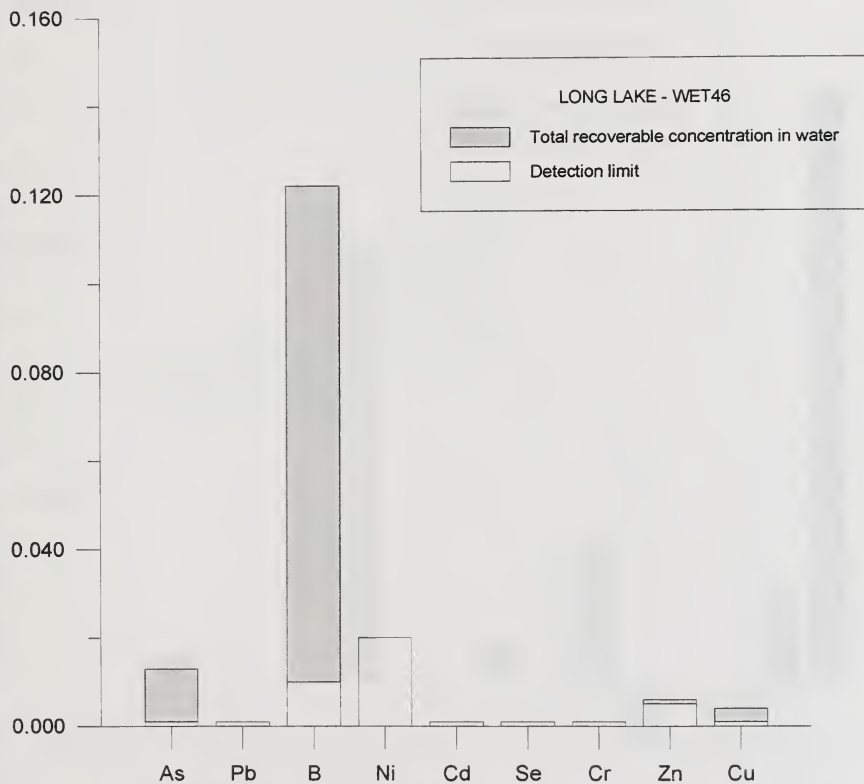
Primary bedrock geologic unit 211CLRD

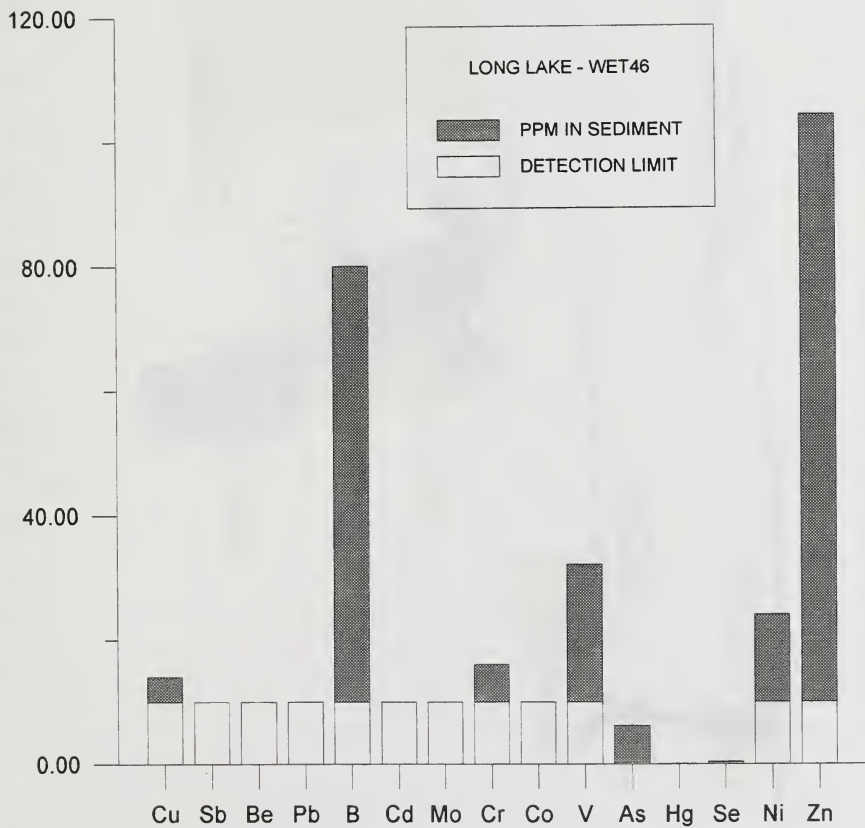
Annual Precipitation in Inches

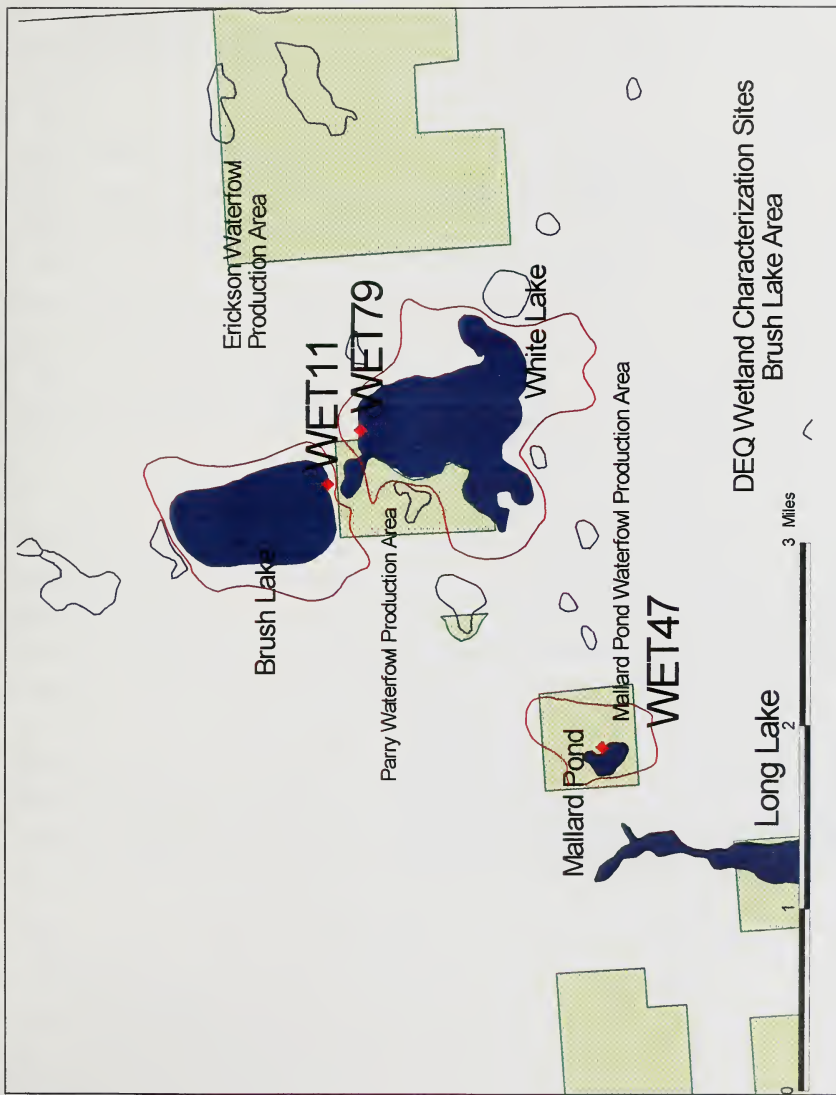




Concentrations in Milligrams per liter







Wetland: MALLARD POND

Site Code: WET47

7.5 Minute Quad: DAGMAR

Lat: 48 34 25

Long: 104 8 20

Mean Annual Precipitation in Inches: 13.00

Mean Annual Potential Evaporation (Penman) in Inches: 36.00

'Net Precipitation' in Inches: -23.00

Site does not have a mapped surface inlet.

Site has a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 17 acres

Area of contributing drainage basin: 160 acres

Mapped elevation of wetland surface: 1953 ft

Maximum elevation within drainage basin: 1993 ft

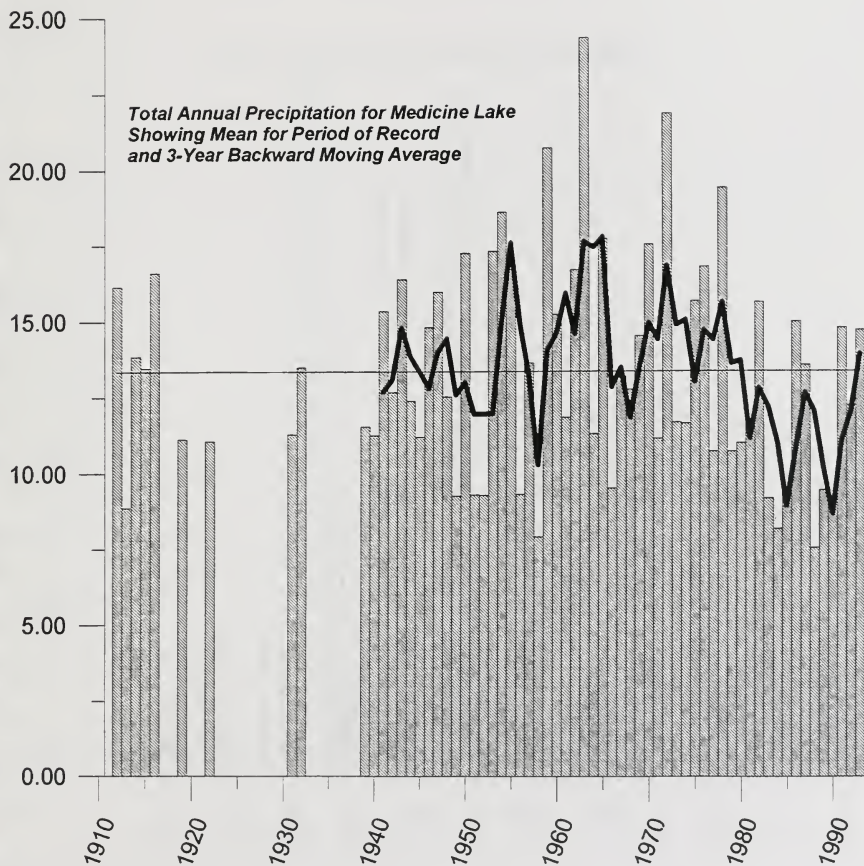
Net relief of contributing basin: 40 ft

COE Hydrogeomorphic class: FRINGE

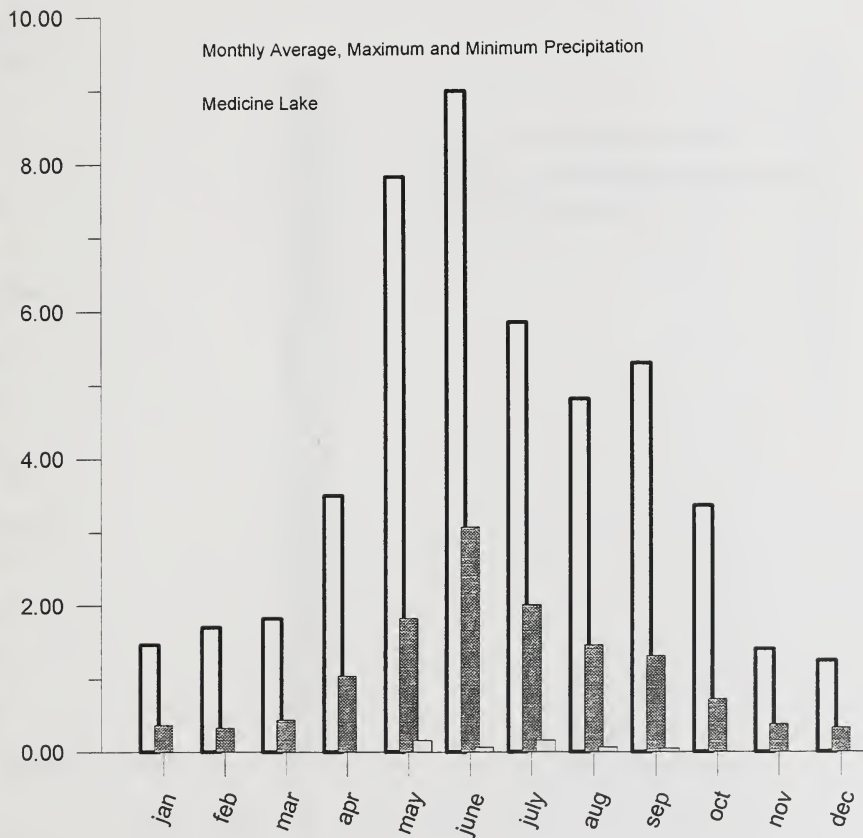
Primary surficial geologic unit 1120TSH

Primary bedrock geologic unit 125FRUN

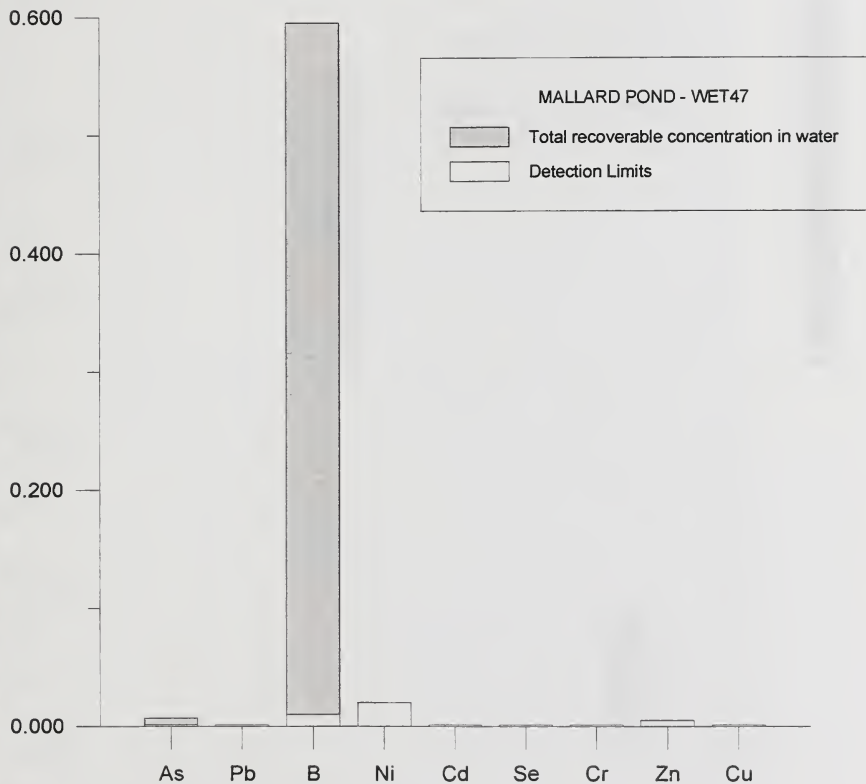
Total Annual Precipitation in Inches

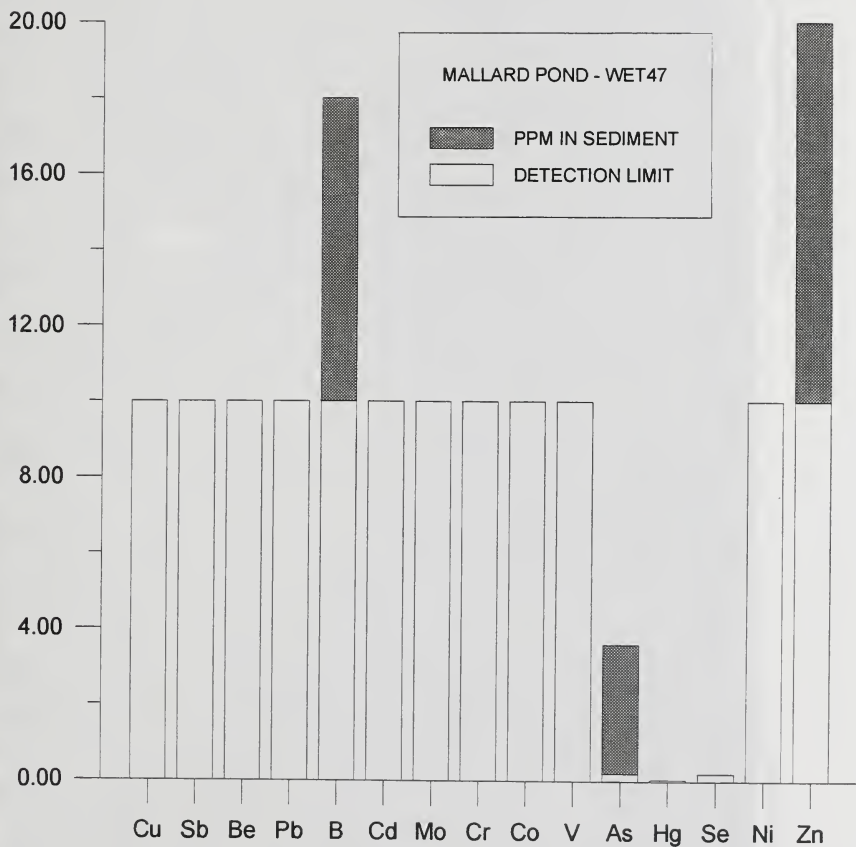


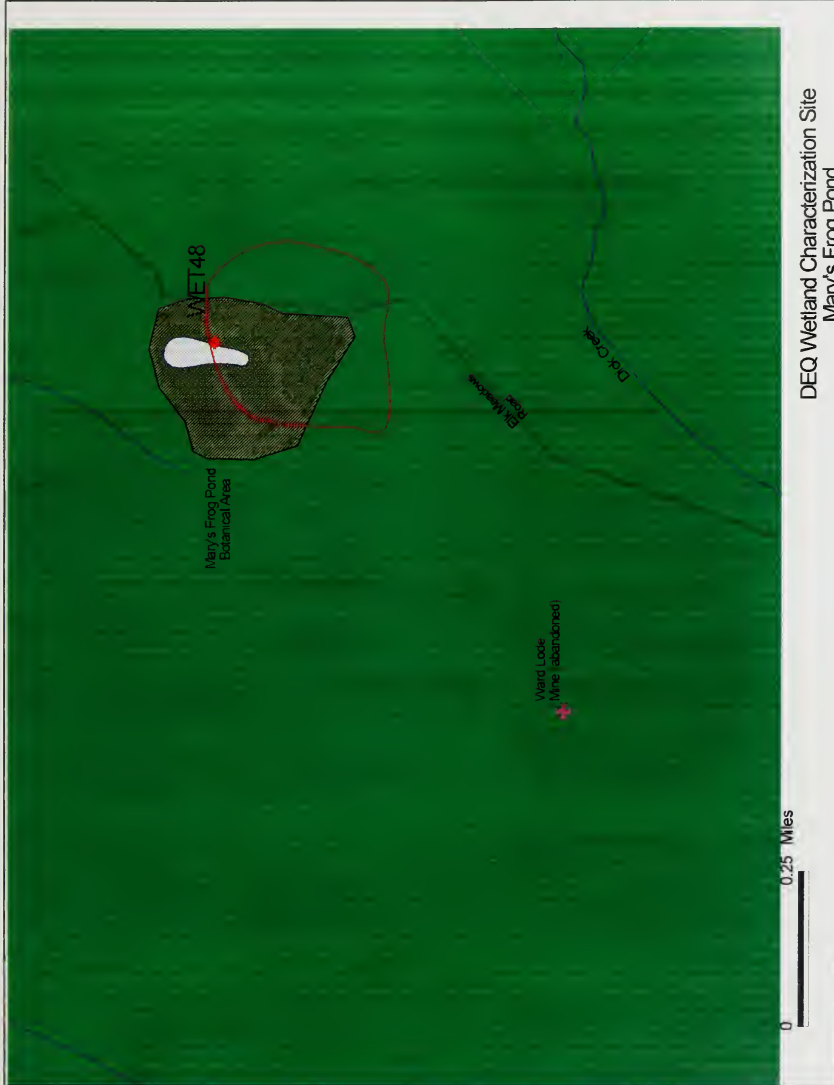
Inches Precipitation



Concentrations in Milligrams per liter







DEQ Wetland Characterization Site
Mary's Frog Pond

Wetland: MARY'S FROG POND BOTANICAL AREA

Site Code: WET48

7.5 Minute Quad: DICK CREEK

Lat: 46 42 12

Long: 114 20 57

Mean Annual Precipitation in Inches: 50.00

Mean Annual Potential Evaporation (Penman) in Inches: 30.00

'Net Precipitation' in Inches: 20.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 3 acres

Area of contributing drainage basin: 48 acres

Mapped elevation of wetland surface: 5750 ft

Maximum elevation within drainage basin: 6100 ft

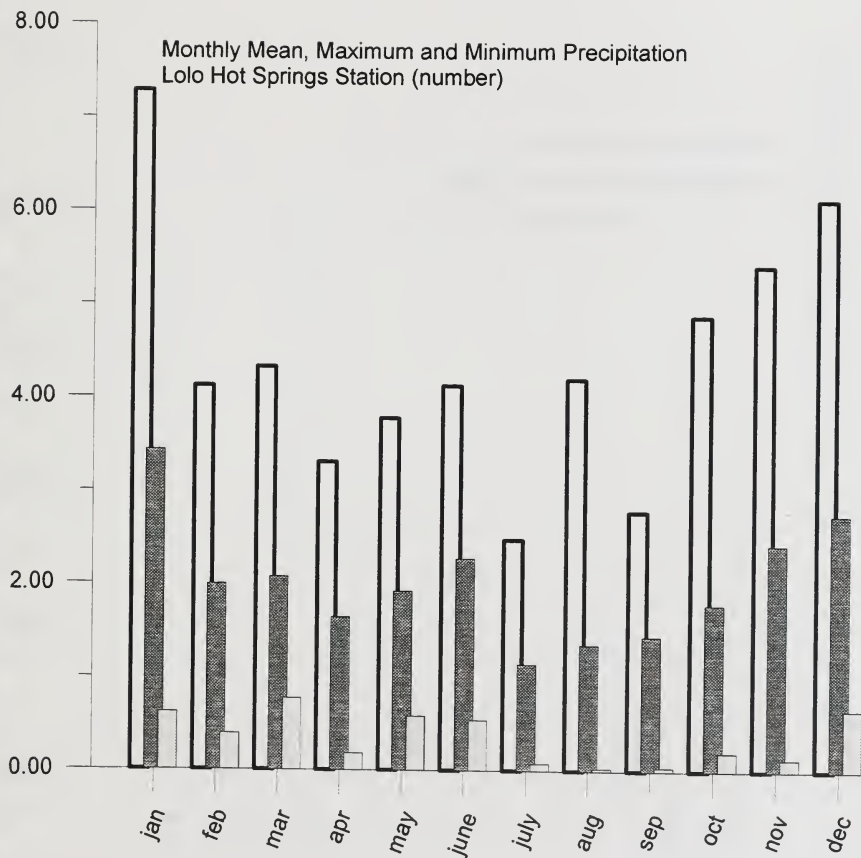
Net relief of contributing basin: 350 ft

COE Hydrogeomorphic class: DEPRESSIONAL

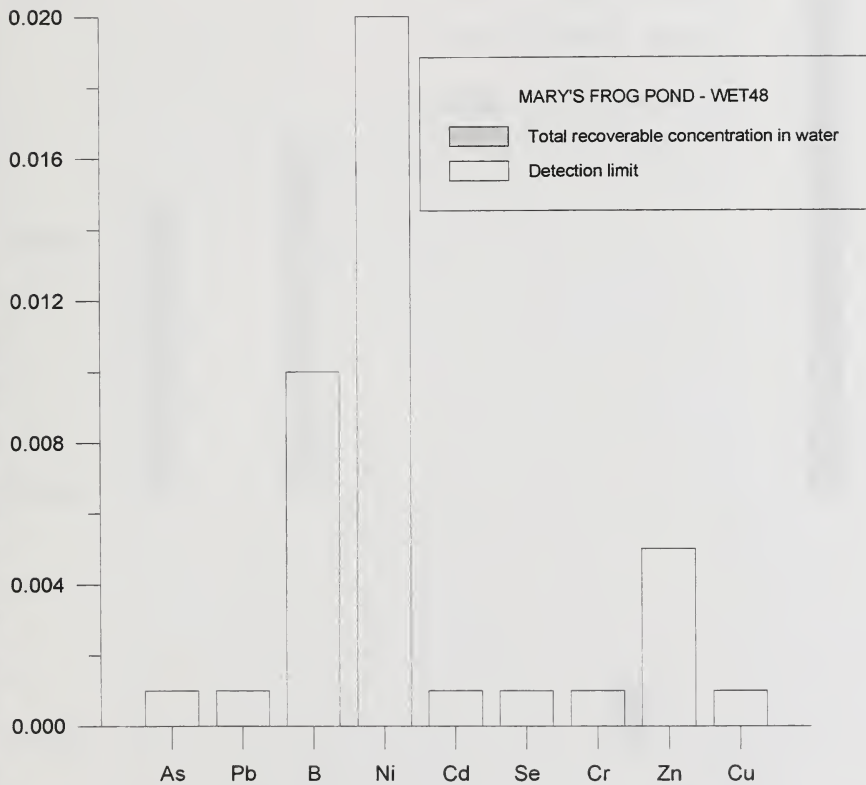
Primary surficial geologic unit

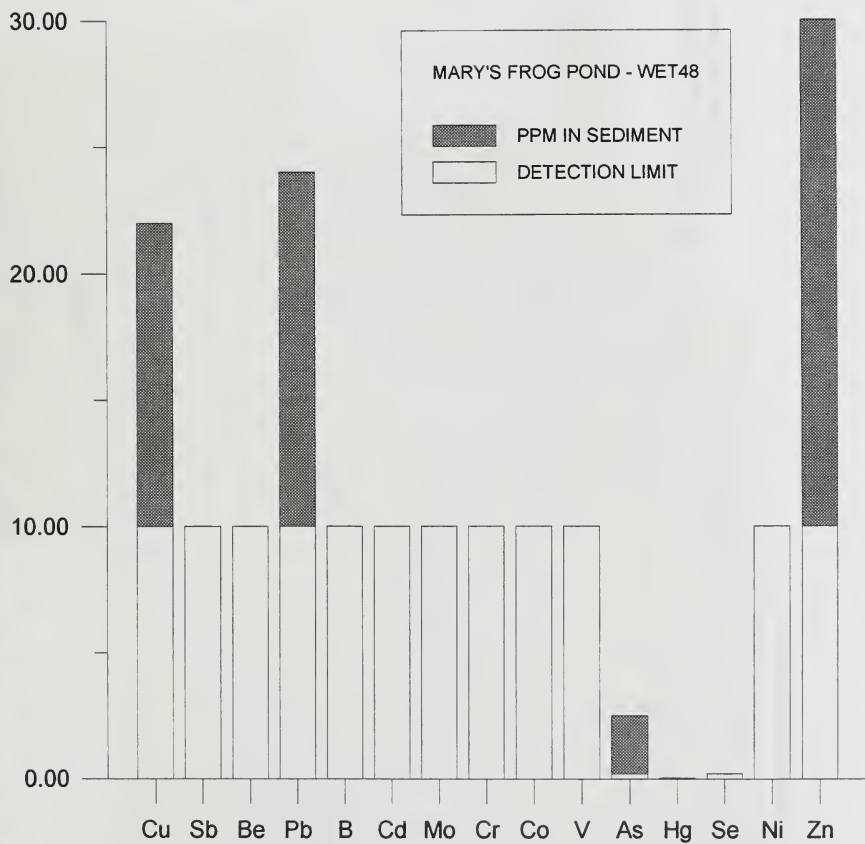
Primary bedrock geologic unit 400RVLL

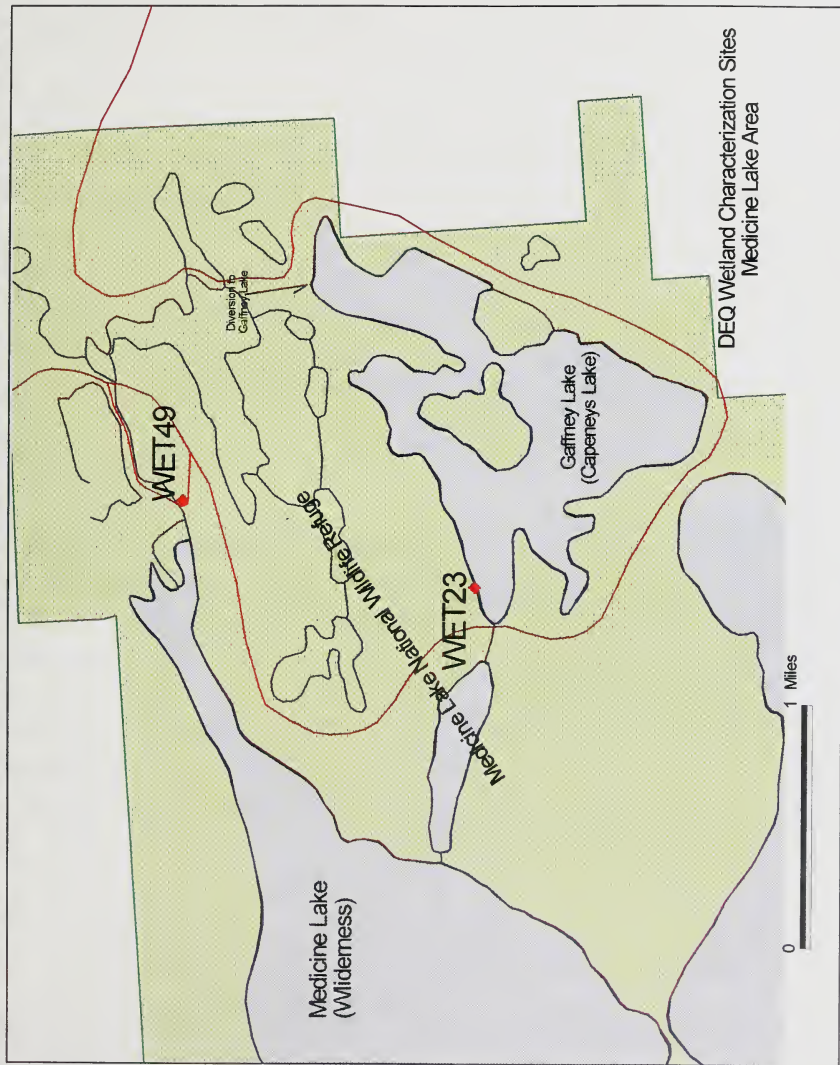
Monthly Mean, Maximum and Minimum Precipitation
Lolo Hot Springs Station (number)



Concentrations in Milligrams per liter







Wetland: MEDICINE LAKE AT LAKE CREEK INLET

Site Code: WET49

7.5 Minute Quad: MEDICINE LAKE

Lat: 48 29 40

Long: 104 19 30

Mean Annual Precipitation in Inches:

13.00

Mean Annual Potential Evaporation (Penman) in Inches:

37.00

'Net Precipitation' in Inches:

-24.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is artificially impounded.

Site has significant water imports.

Mapped area of wetland:

8814 acres

Area of contributing drainage basin:

292170 acres

Mapped elevation of wetland surface:

1935 ft

Maximum elevation within drainage basin:

2408 ft

Net relief of contributing basin:

473 ft

COE Hydrogeomorphic class:

FRINGE

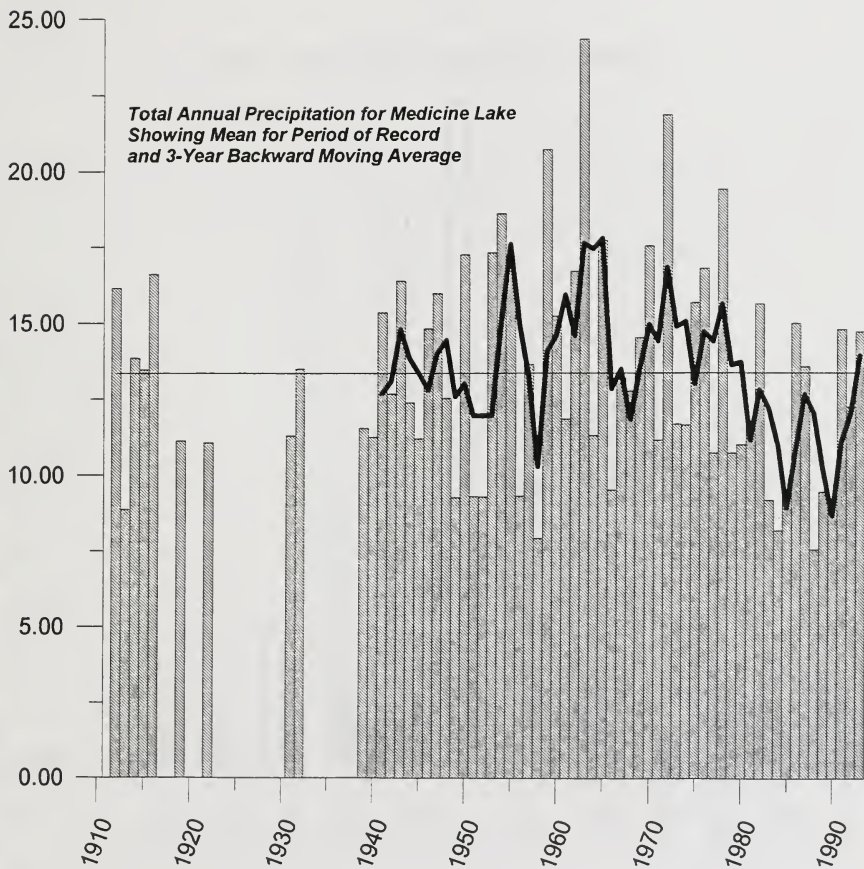
Primary surficial geologic unit

1120TSH

Primary bedrock geologic unit

125FRUN

Total Annual Precipitation in Inches



Inches Precipitation

10.00

Monthly Average, Maximum and Minimum Precipitation

Medicine Lake

8.00

6.00

4.00

2.00

0.00

jan

feb

mar

apr

may

june

july

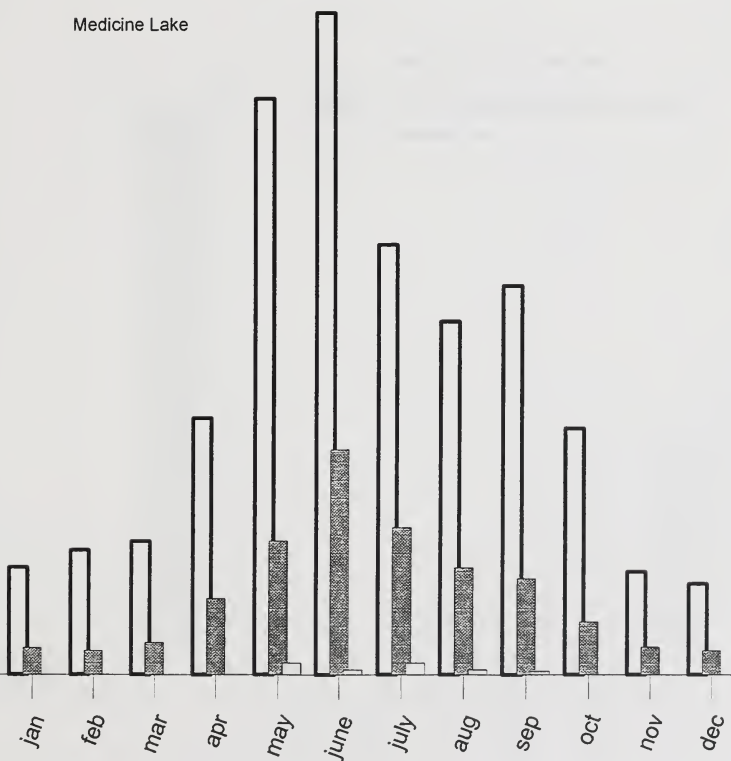
aug

sep

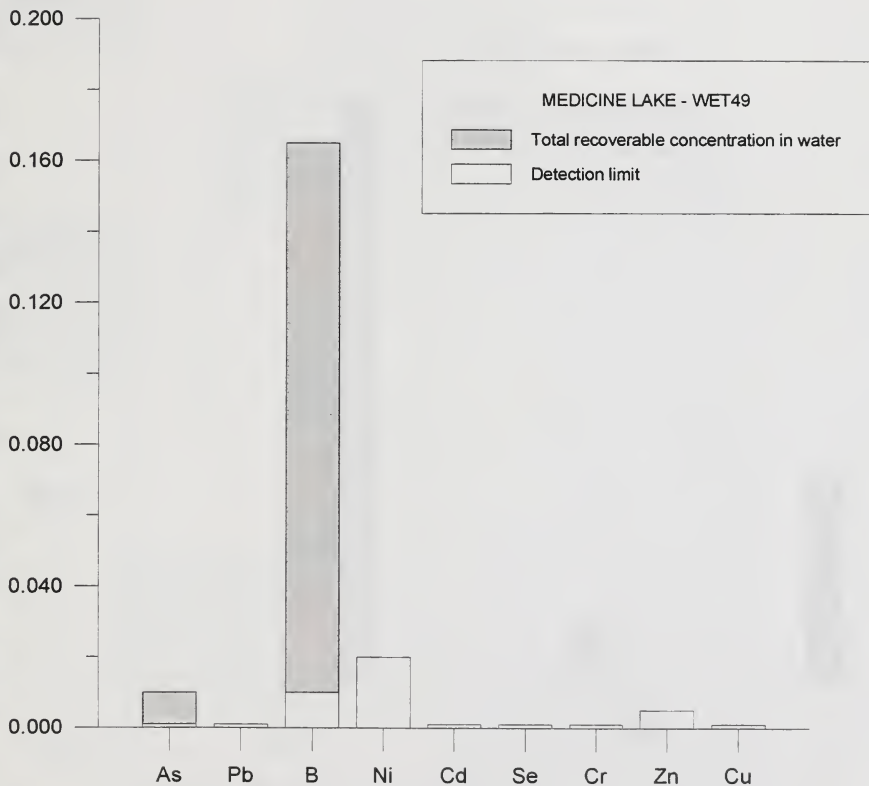
oct

nov

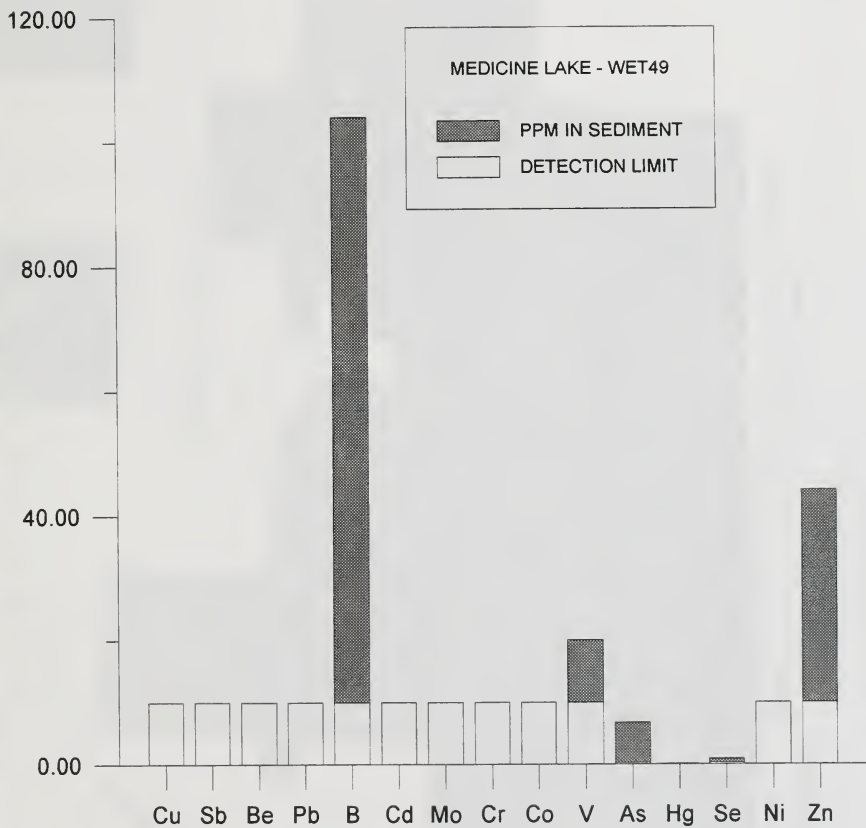
dec



Concentrations in Milligrams per liter



HNO3 - Extractable Sediment Concentrations in PPM





Wetland: MIKILLOP CREEK WETLAND

Site Code: WET50

7.5 Minute Quad: FISHER MOUNTAIN

Lat: 48 8 17

Long: 115 16 0

Mean Annual Precipitation in Inches:	25.00
Mean Annual Potential Evaporation (Penman) in Inches:	28.00
'Net Precipitation' in Inches:	-3.00

Site has a mapped surface inlet.

Site does not have a mapped surface outlet.

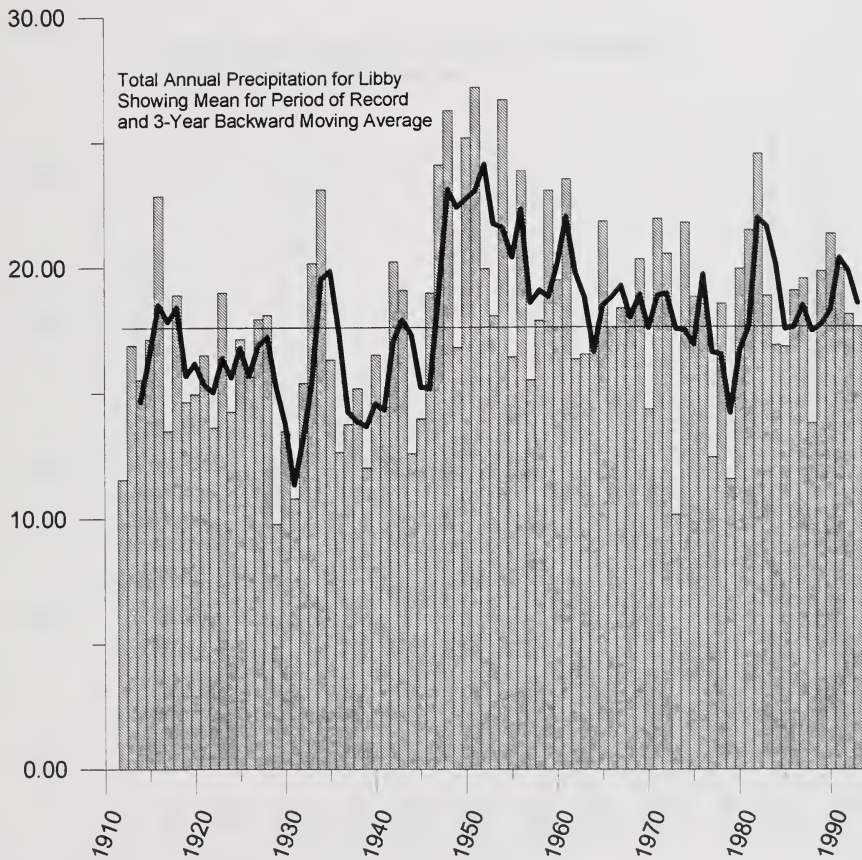
Site is not known to be artificially impounded.

Site does not have known significant water imports.

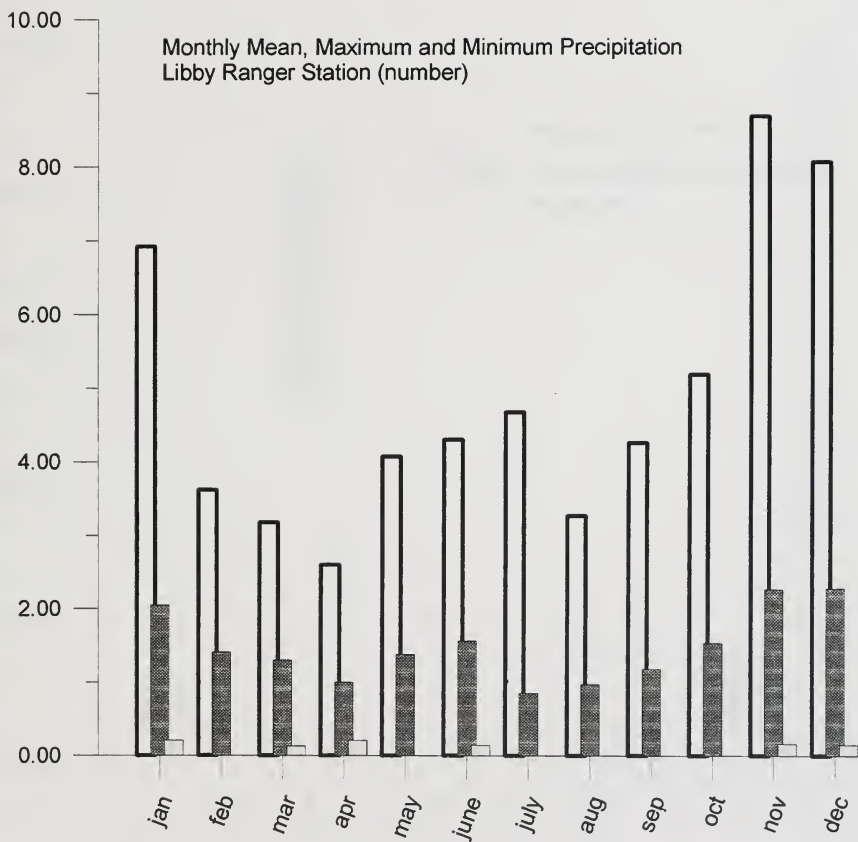
Mapped area of wetland:	2 acres
Area of contributing drainage basin:	620 acres
Mapped elevation of wetland surface:	3032 ft
Maximum elevation within drainage basin:	5988 ft
Net relief of contributing basin:	2956 ft

COE Hydrogeomorphic class:	DEPRESSIONAL
Primary surficial geologic unit	112DRFT
Primary bedrock geologic unit	400BELT

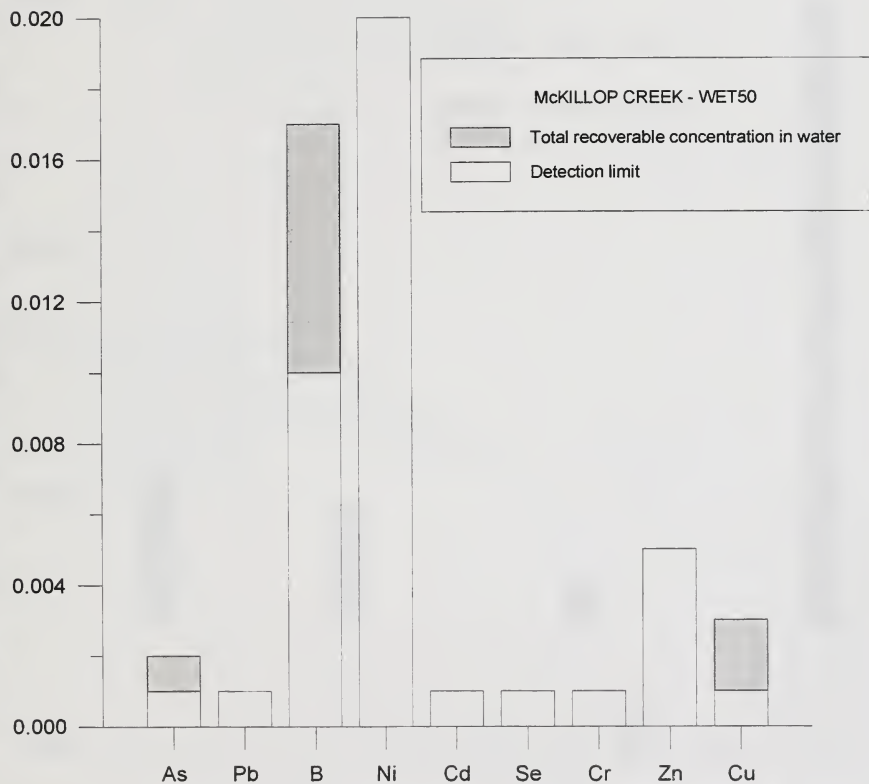
Annual Precipitation in Inches

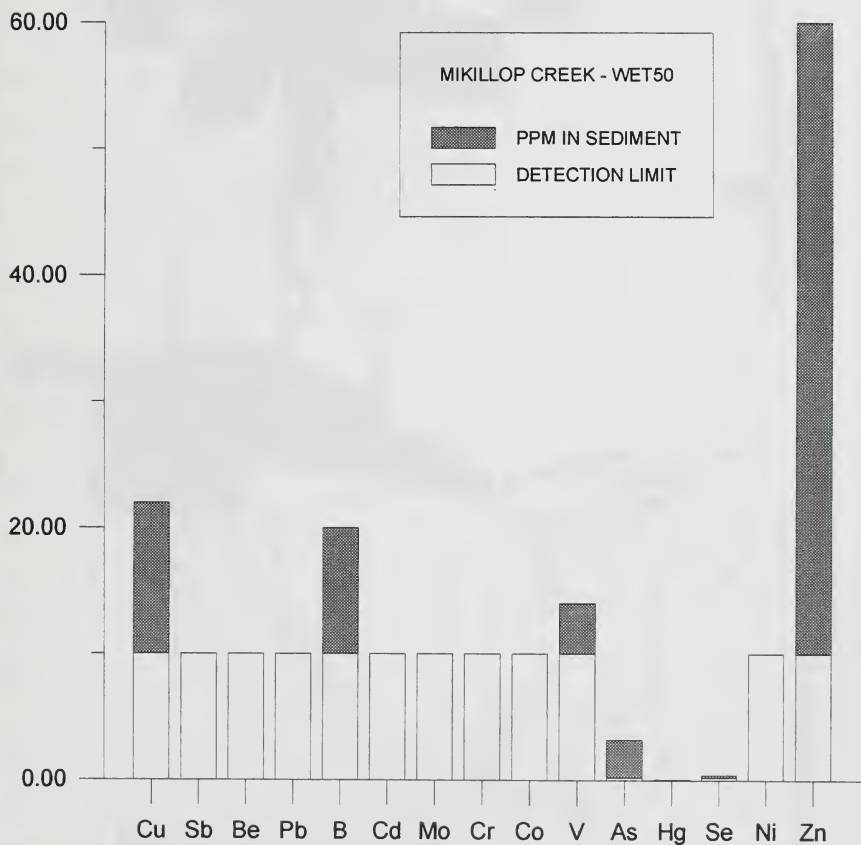


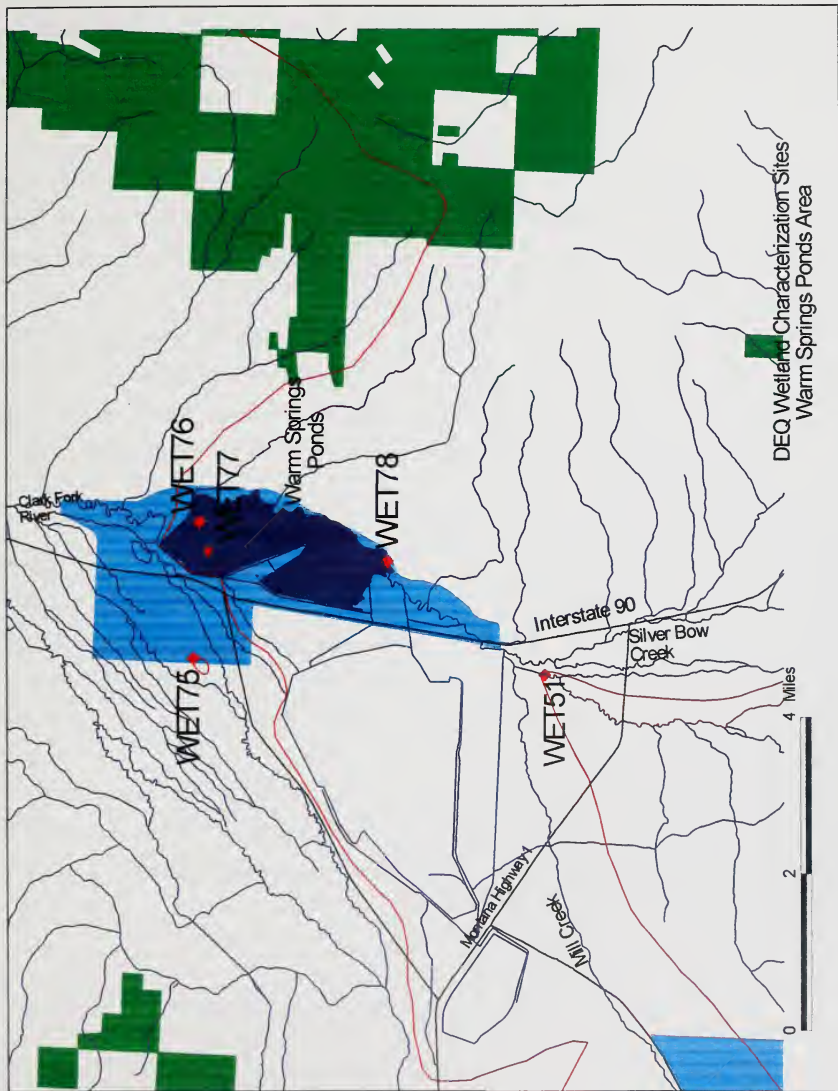
Monthly Mean, Maximum and Minimum Precipitation
Libby Ranger Station (number)



Concentrations in Milligrams per liter







Wetland: MILL-WILLOW/SILVERBOW WETLAND

Site Code: WET51

7.5 Minute Quad: OPPORTUNITY

Lat: 46 6 35

Long: 112 48 20

Mean Annual Precipitation in Inches:	11.00
Mean Annual Potential Evaporation (Penman) in Inches:	33.00
'Net Precipitation' in Inches:	-22.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is not known to be artificially impounded.

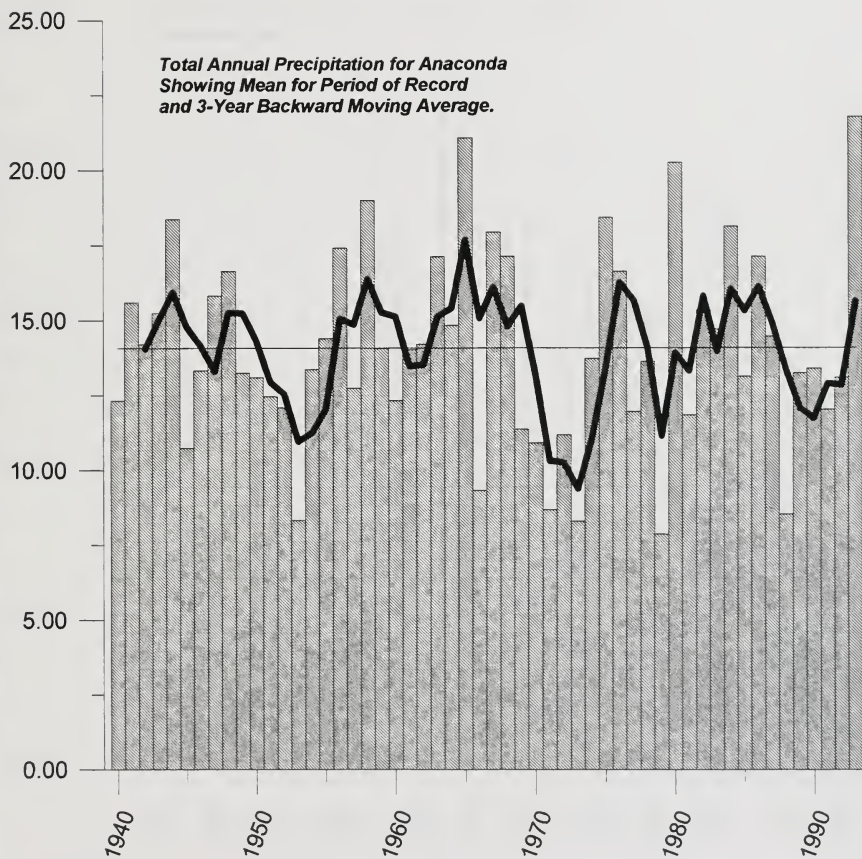
Site does not have known significant water imports.

Mapped area of wetland:	150 acres
Area of contributing drainage basin:	17980 acres
Mapped elevation of wetland surface:	4820 ft
Maximum elevation within drainage basin:	7362 ft
Net relief of contributing basin:	2542 ft

COE Hydrogeomorphic class:	RIVERINE
Primary surficial geologic unit	110ALVM
Primary bedrock geologic unit	120SDMS

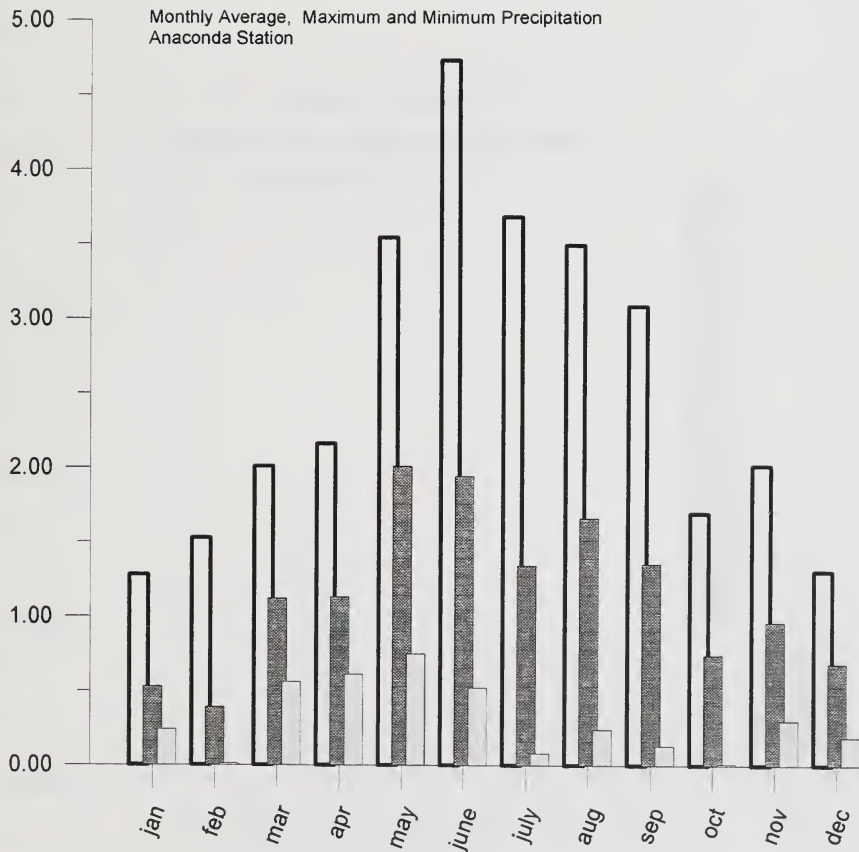
Annual Precipitation in Inches

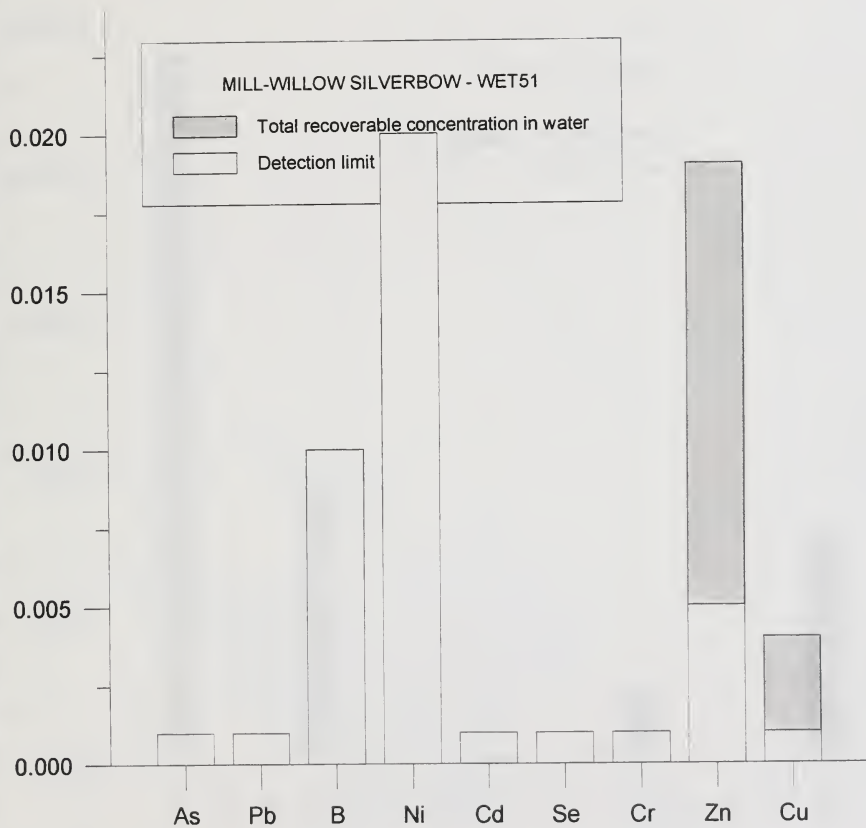
**Total Annual Precipitation for Anaconda
Showing Mean for Period of Record
and 3-Year Backward Moving Average.**

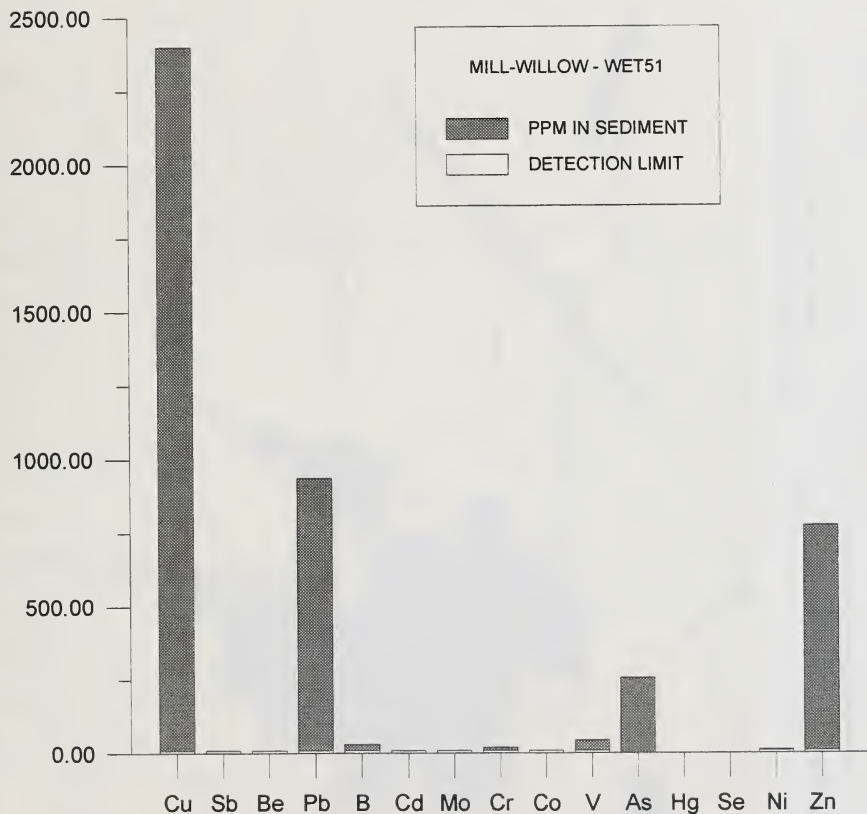


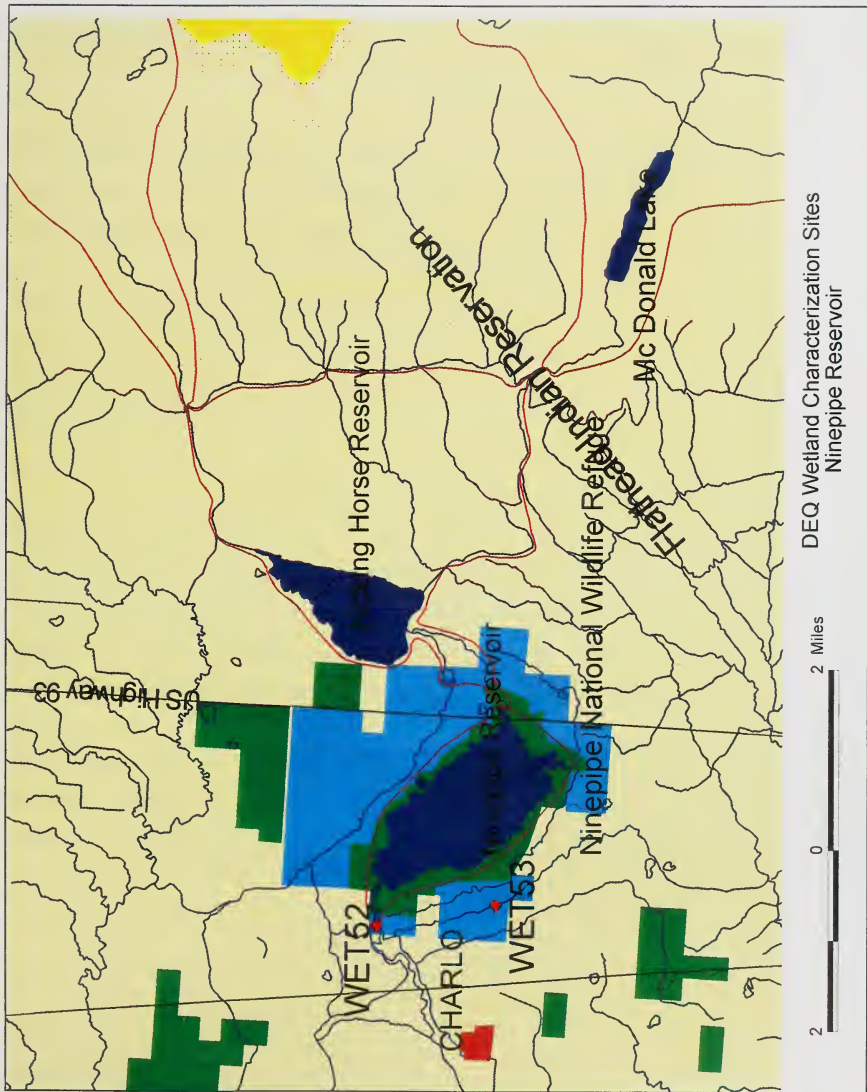
Inches Precipitation

Monthly Average, Maximum and Minimum Precipitation
Anaconda Station









Wetland: NINEPIPE RESERVOIR OUTLET

Site Code: WET52

7.5 Minute Quad: CHARLO

Lat: 47 27 20

Long: 114 8 50

Mean Annual Precipitation in Inches:	17.00
Mean Annual Potential Evaporation (Penman) in Inches:	35.00
'Net Precipitation' in Inches:	-18.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

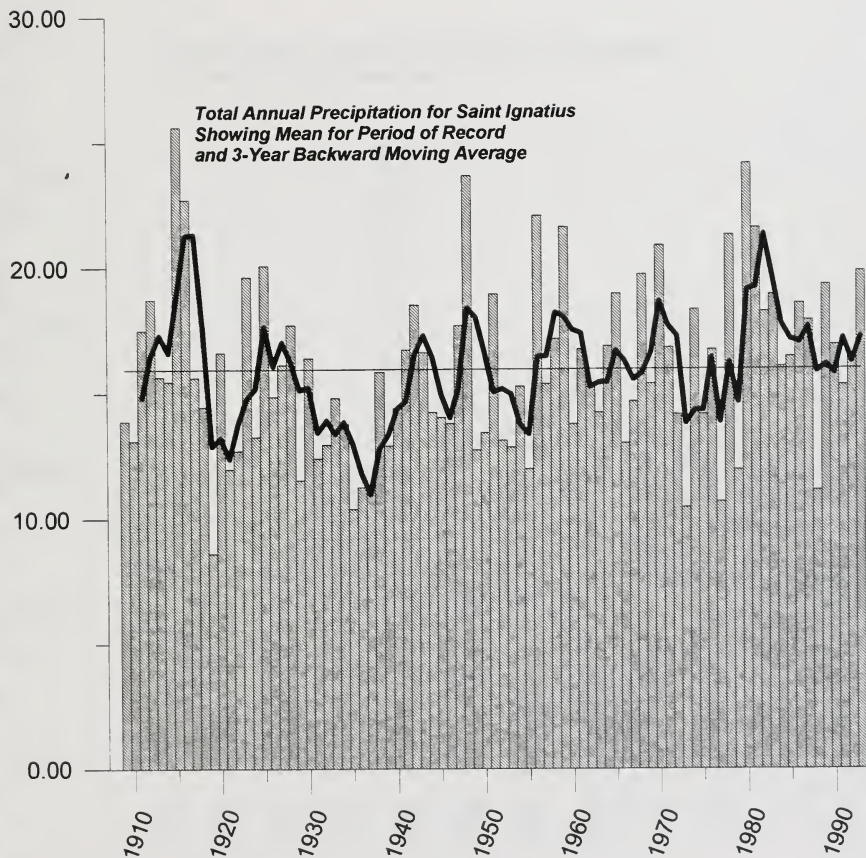
Site is artificially impounded.

Site has significant water imports.

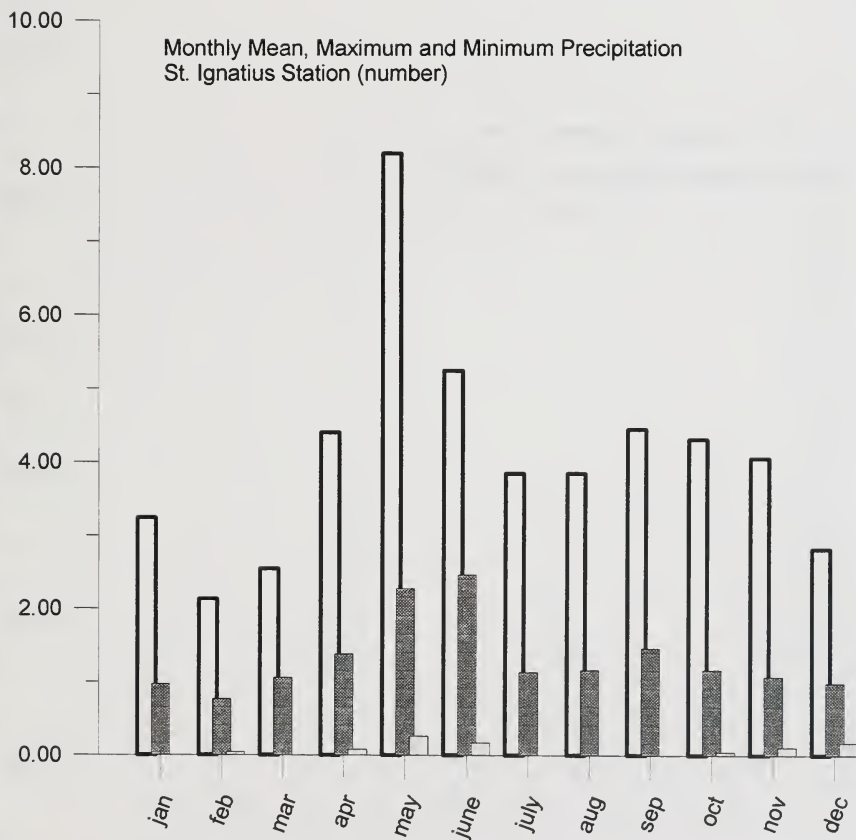
Mapped area of wetland:	100 acres
Area of contributing drainage basin:	1810 acres
Mapped elevation of wetland surface:	2980 ft
Maximum elevation within drainage basin:	9820 ft
Net relief of contributing basin:	6840 ft

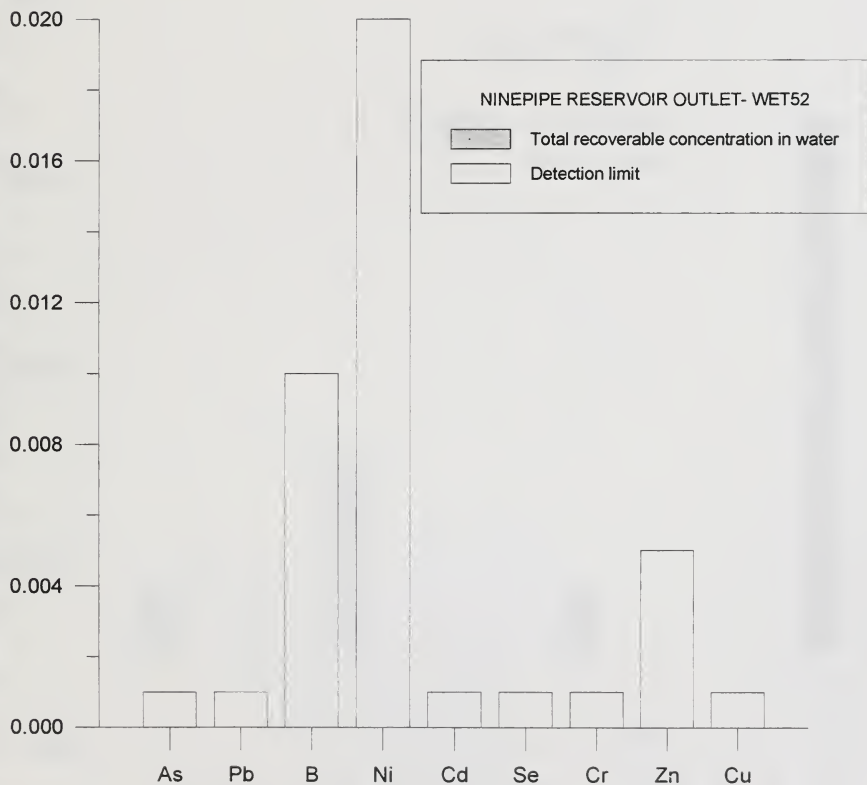
COE Hydrogeomorphic class:	RIVERINE
Primary surficial geologic unit	112DRFT
Primary bedrock geologic unit	400BELT

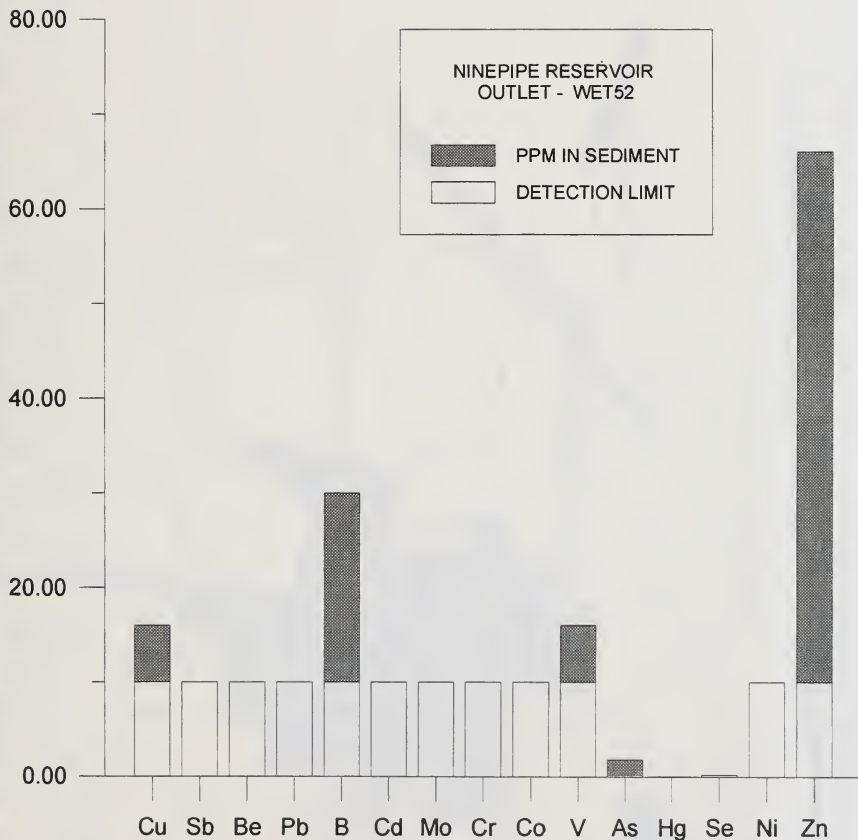
Annual Precipitation in Inches

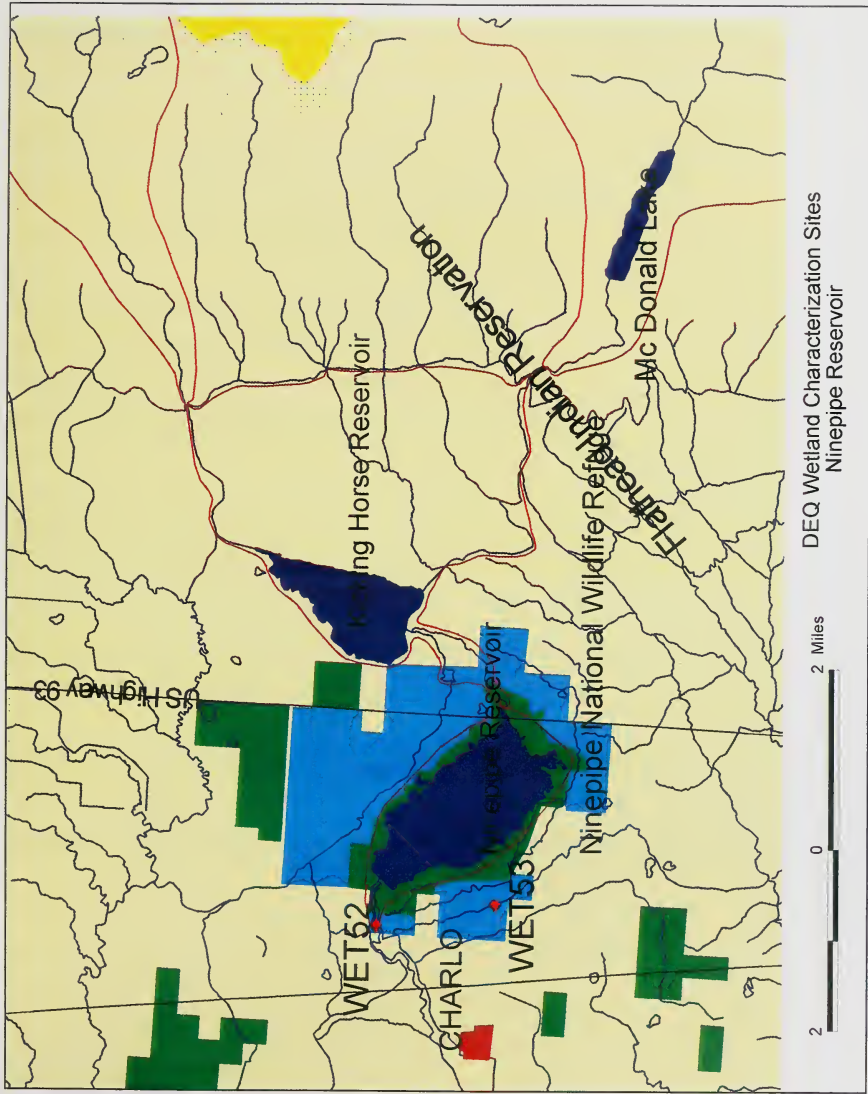


Monthly Mean, Maximum and Minimum Precipitation
St. Ignace Station (number)









DEQ Wetland Characterization Sites
Ninepipe Reservoir

2 0 2 Miles

Wetland: NINEPIPE RESERVOIR POTHOLE

Site Code: WET53

7.5 Minute Quad: CHARLO

Lat: 47 26 13

Long: 114 8 25

Mean Annual Precipitation in Inches:	17.00
Mean Annual Potential Evaporation (Penman) in Inches:	32.00
'Net Precipitation' in Inches:	-15.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

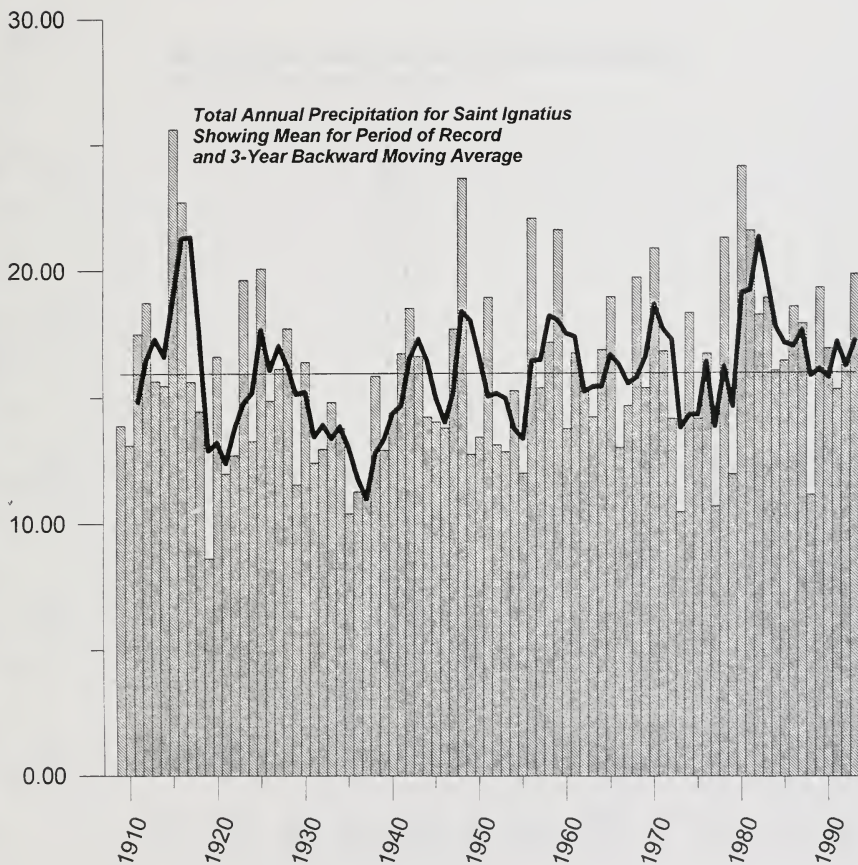
Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland:	0 acres
Area of contributing drainage basin:	3 acres
Mapped elevation of wetland surface:	2970 ft
Maximum elevation within drainage basin:	3005 ft
Net relief of contributing basin:	35 ft

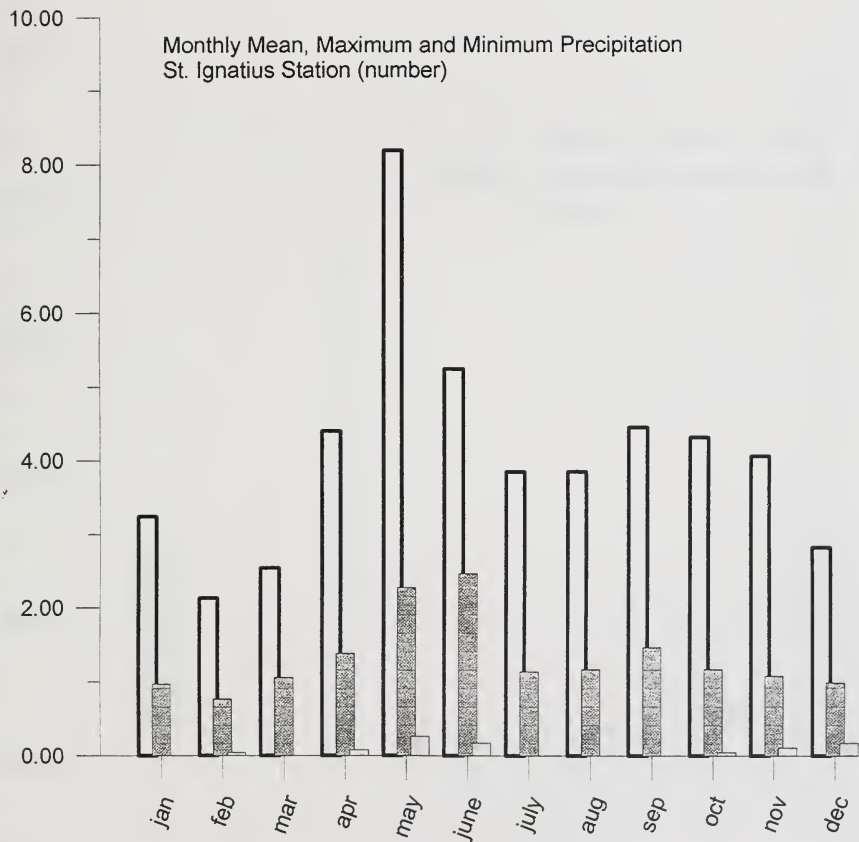
COE Hydrogeomorphic class:	DEPRESSIONAL
Primary surficial geologic unit	112DRFT
Primary bedrock geologic unit	400BELT

Annual Precipitation in Inches

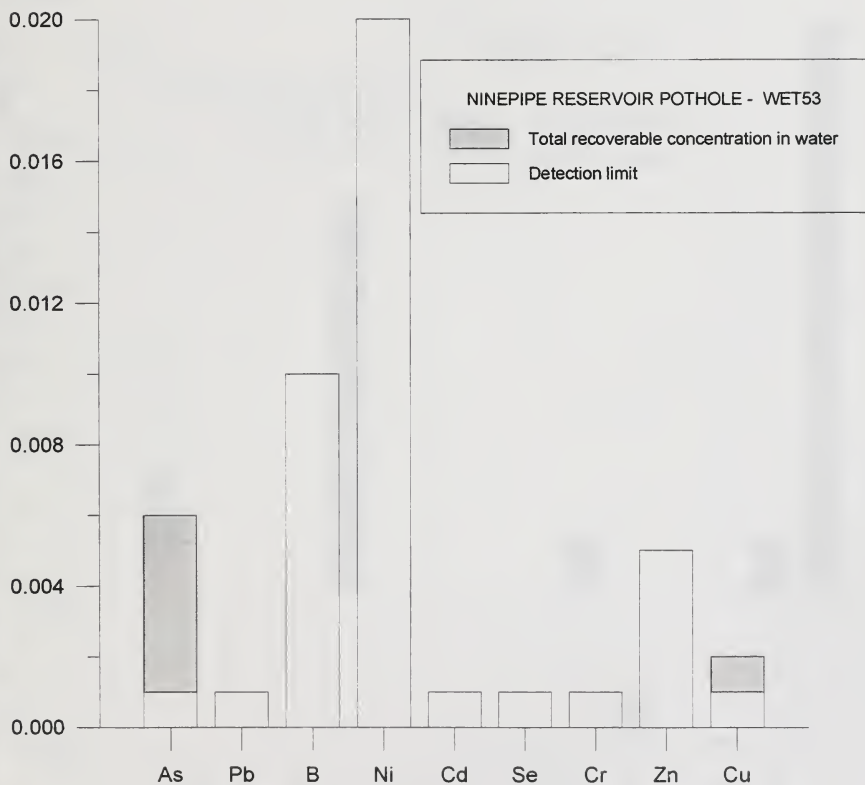


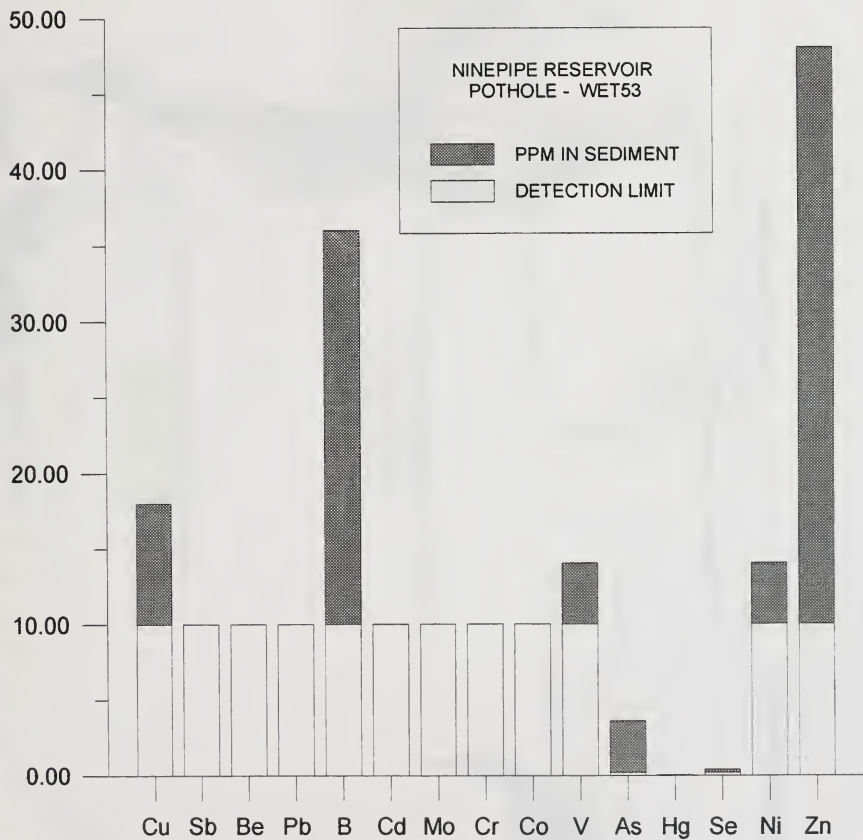
Inches Precipitation

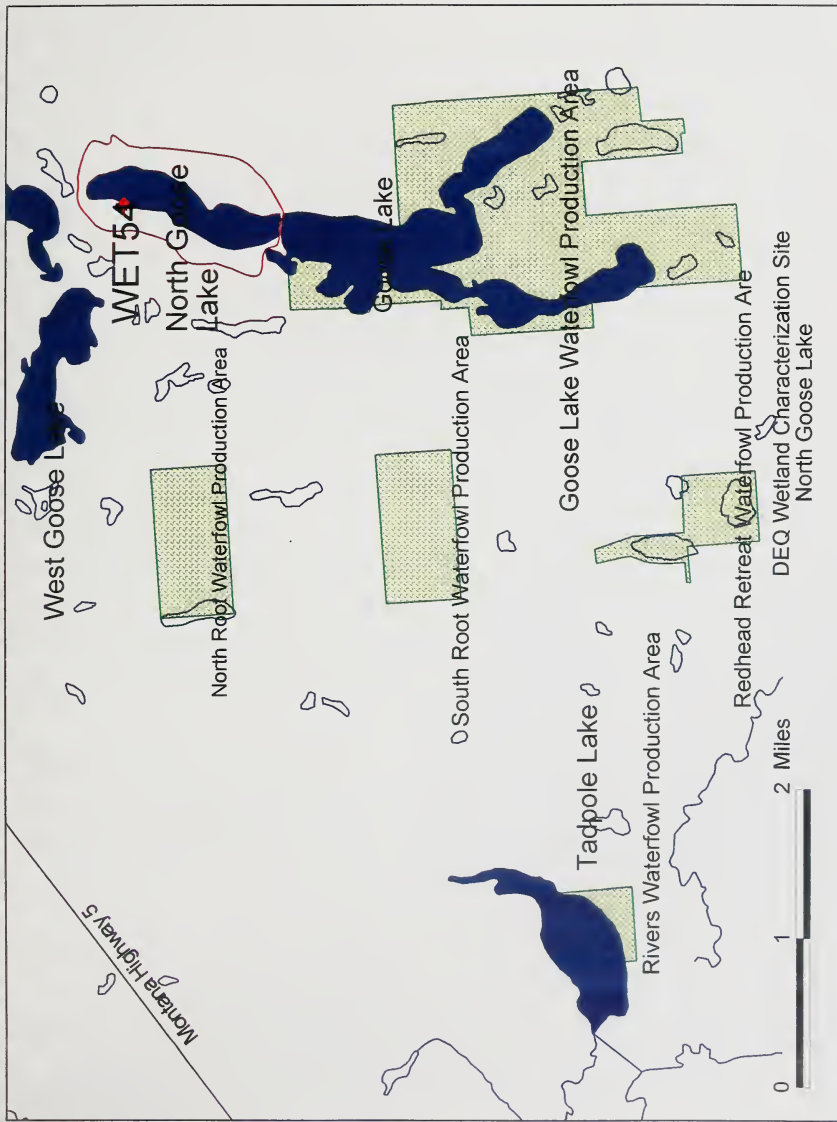
Monthly Mean, Maximum and Minimum Precipitation
St. Ignatius Station (number)



Concentrations in Milligrams per liter







Wetland: NORTH GOOSE LAKE

Site Code: WET54

7.5 Minute Quad: WESTBY SOUTH

Lat: 48 50 25

Long: 104 3 35

Mean Annual Precipitation in Inches: 15.00

Mean Annual Potential Evaporation (Penman) in Inches: 36.00

'Net Precipitation' in Inches: -21.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 190 acres

Area of contributing drainage basin: 540 acres

Mapped elevation of wetland surface: 2049 ft

Maximum elevation within drainage basin: 2120 ft

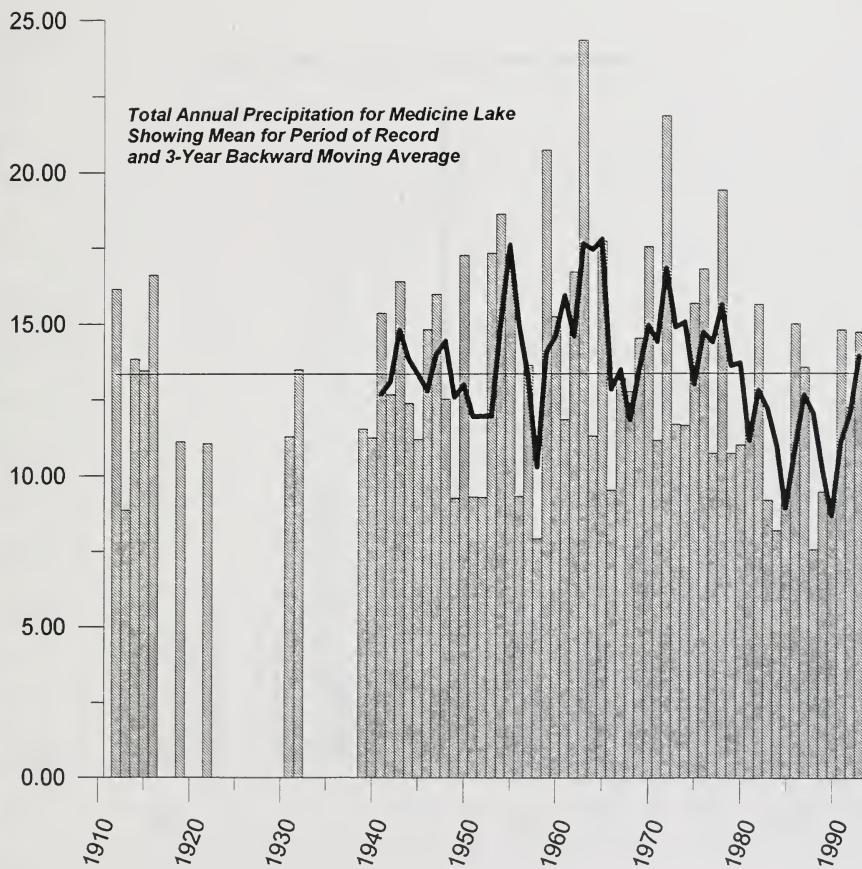
Net relief of contributing basin: 71 ft

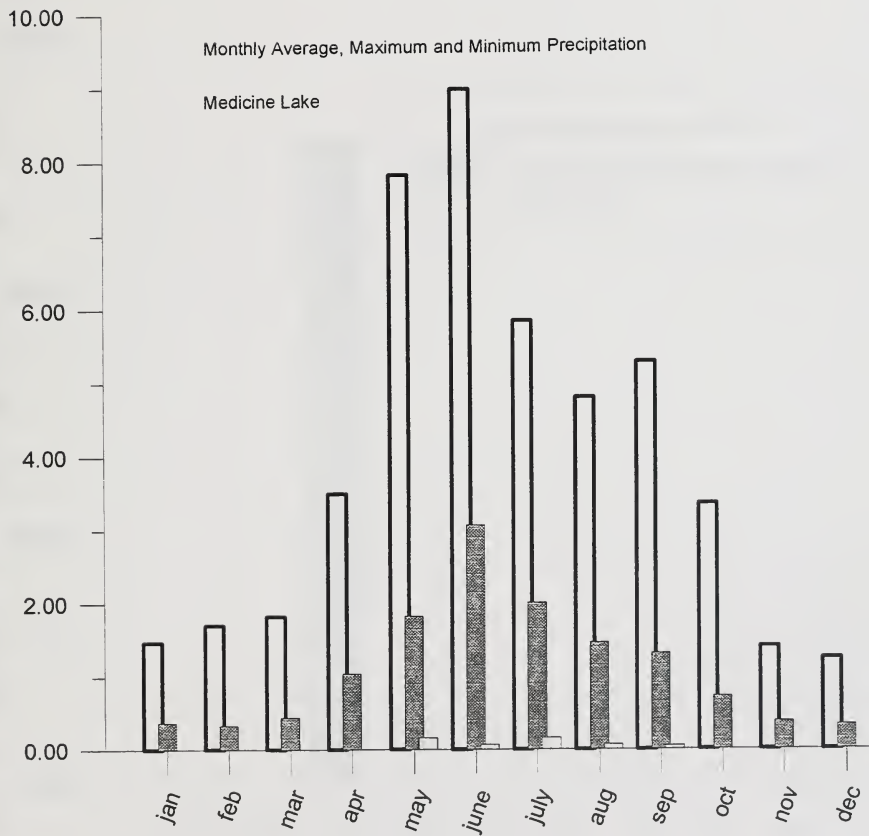
COE Hydrogeomorphic class: FRINGE

Primary surficial geologic unit 1120TSH

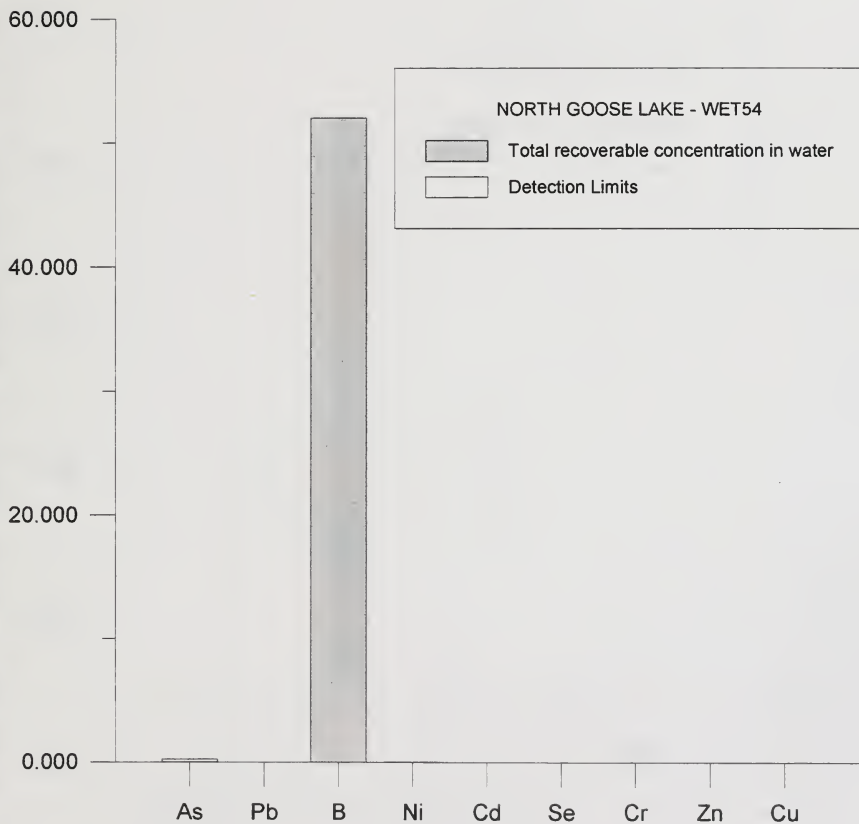
Primary bedrock geologic unit 125FRUN

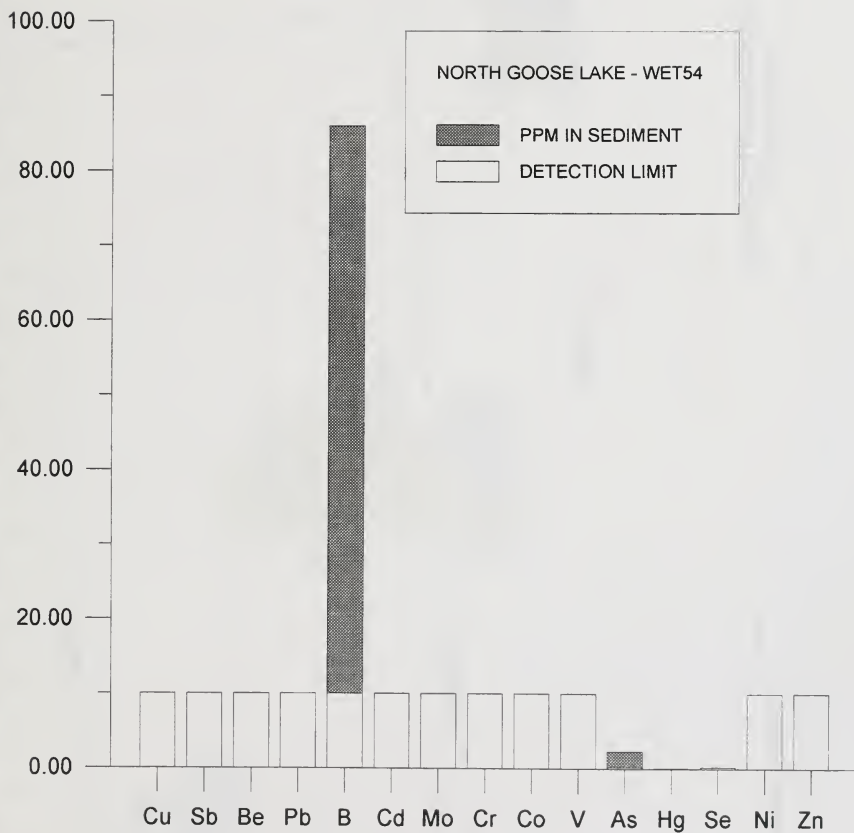
Total Annual Precipitation in Inches

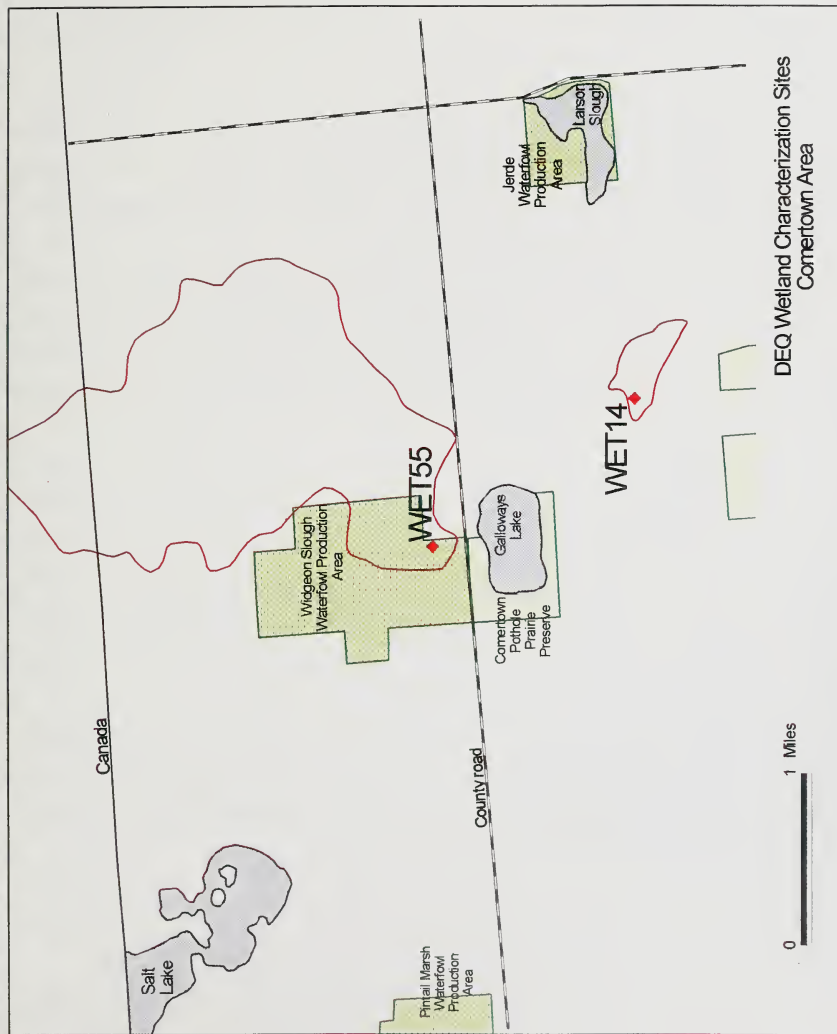




Concentrations in Milligrams per liter







Wetland: NORTH WIDGEON SLOUGH WPA

Site Code: WET55

7.5 Minute Quad: LONE TREE LAKE

Lat: 48 58 10

Long: 104 14 45

Mean Annual Precipitation in Inches: 15.00

Mean Annual Potential Evaporation (Penman) in Inches: 35.00

'Net Precipitation' in Inches: -20.00

Site has a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 73 acres

Area of contributing drainage basin: 1890 acres

Mapped elevation of wetland surface: 2169 ft

Maximum elevation within drainage basin: 2355 ft

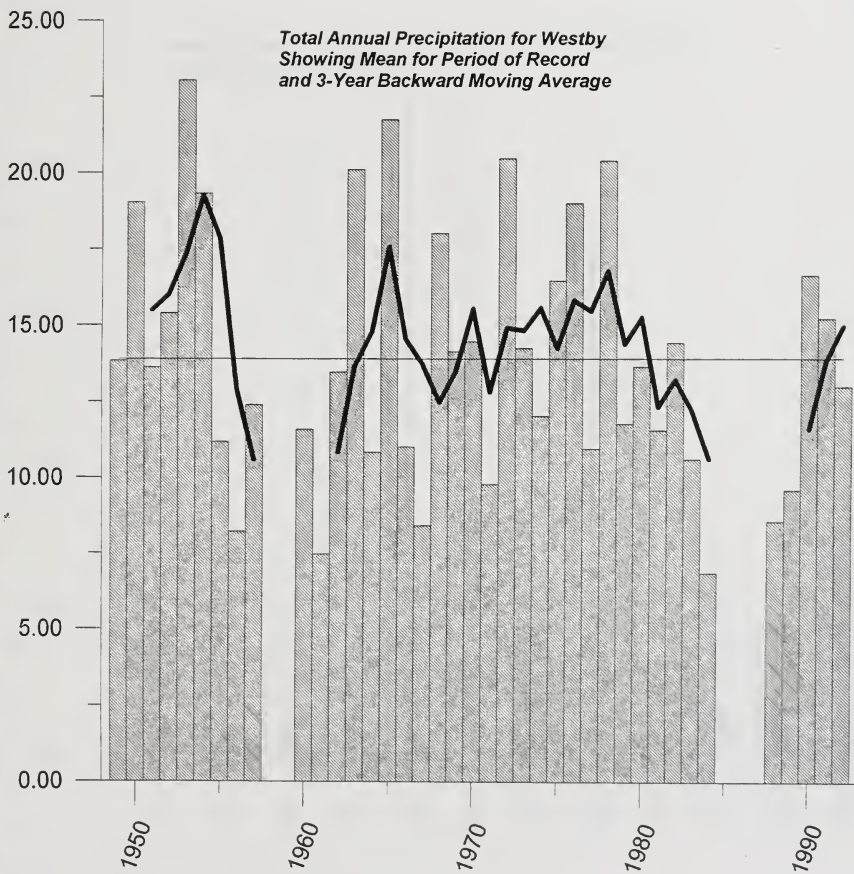
Net relief of contributing basin: 186 ft

COE Hydrogeomorphic class: DEPRESSIONAL

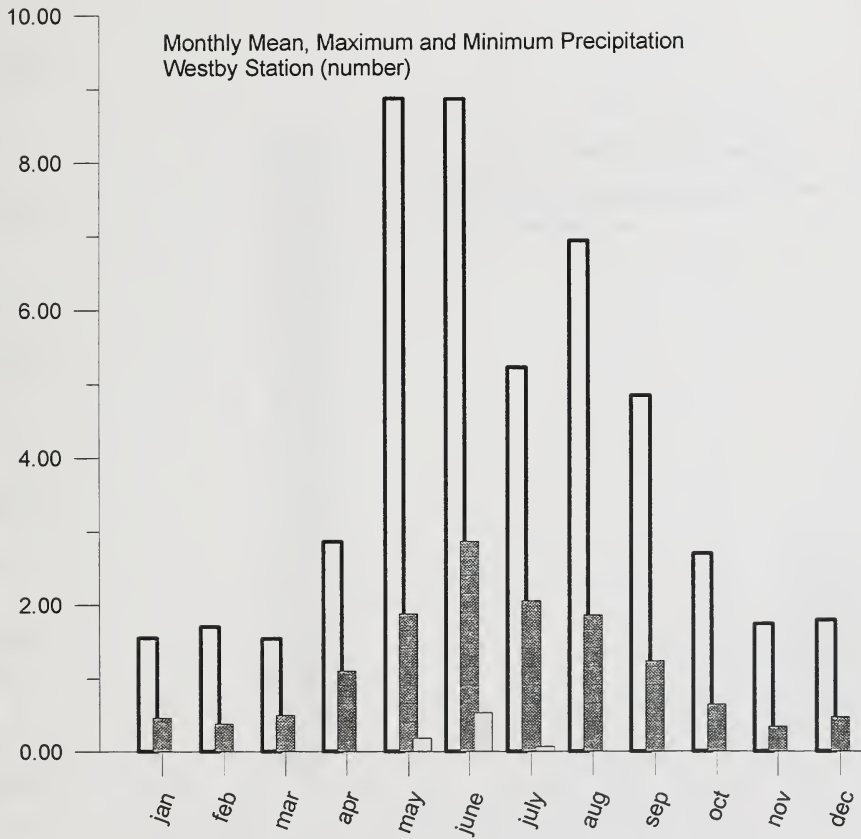
Primary surficial geologic unit 112TILL

Primary bedrock geologic unit 125FRUN

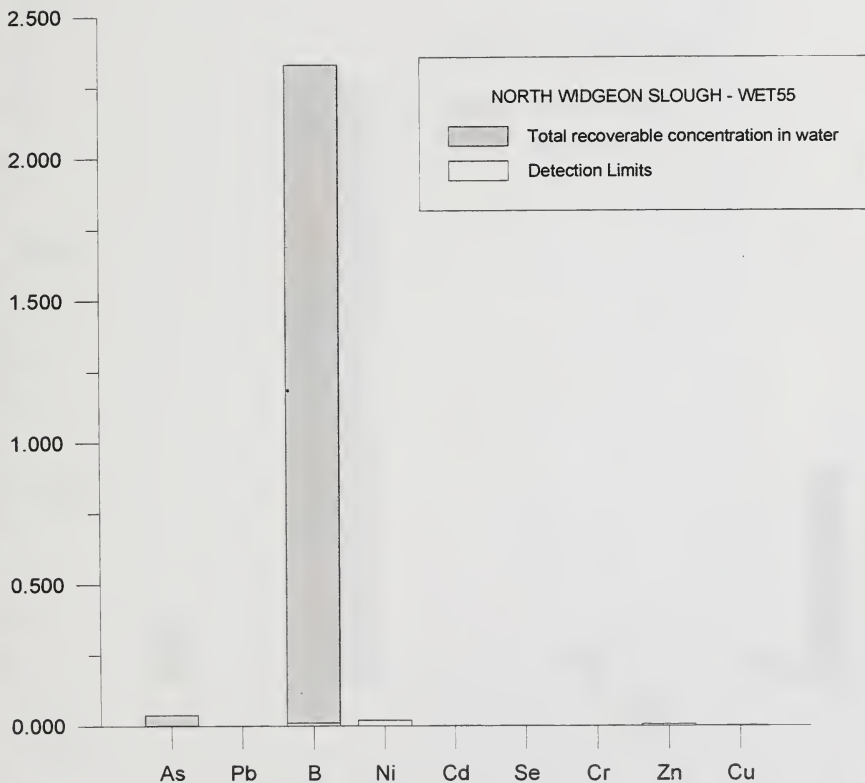
Annual Precipitation in Inches

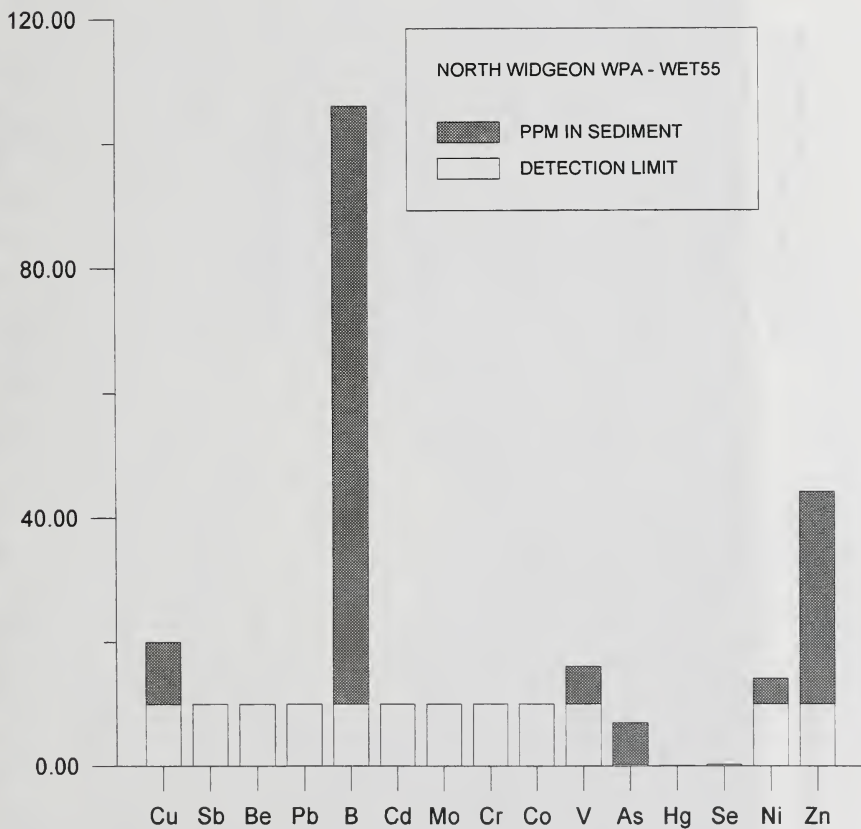


Monthly Mean, Maximum and Minimum Precipitation
Westby Station (number)



Concentrations in Milligrams per liter







Wetland: O'DELL-SKULL CREEK PROPOSED RNA

Site Code: WET56

7.5 Minute Quad: ODELL LAKE

Lat: 45 34 22

Long: 113 11 25

Mean Annual Precipitation in Inches: 25.00

Mean Annual Potential Evaporation (Penman) in Inches: 29.00

'Net Precipitation' in Inches: -4.00

Site does not have a mapped surface inlet.

Site has a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 13 acres

Area of contributing drainage basin: 470 acres

Mapped elevation of wetland surface: 7875 ft

Maximum elevation within drainage basin: 8470 ft

Net relief of contributing basin: 595 ft

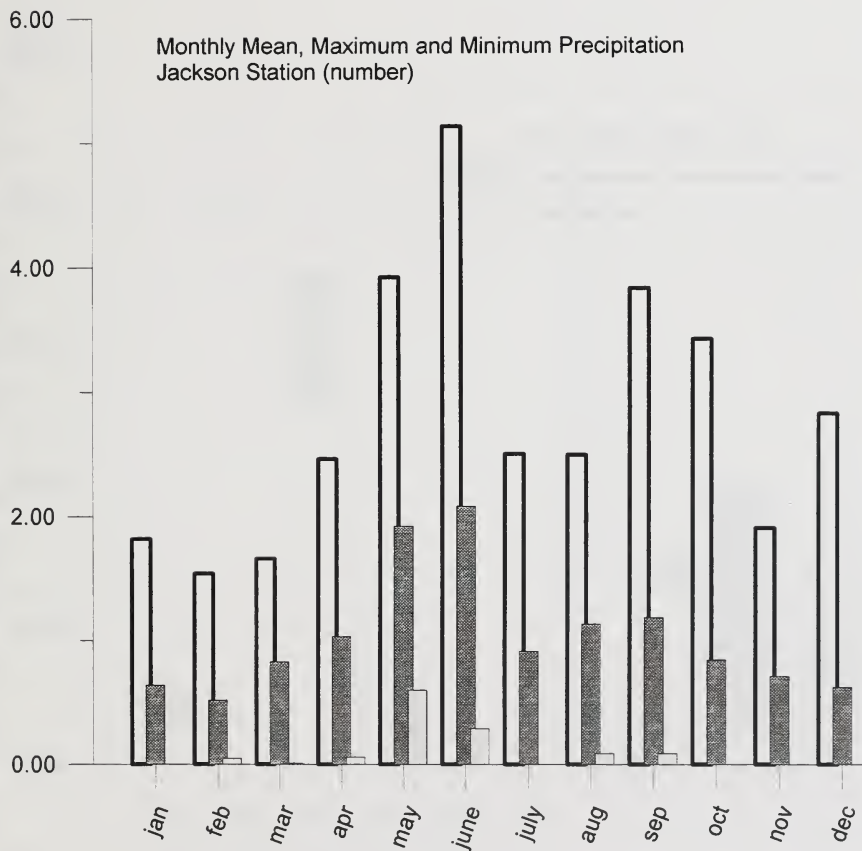
COE Hydrogeomorphic class: RIVERINE

Primary surficial geologic unit 112TILL

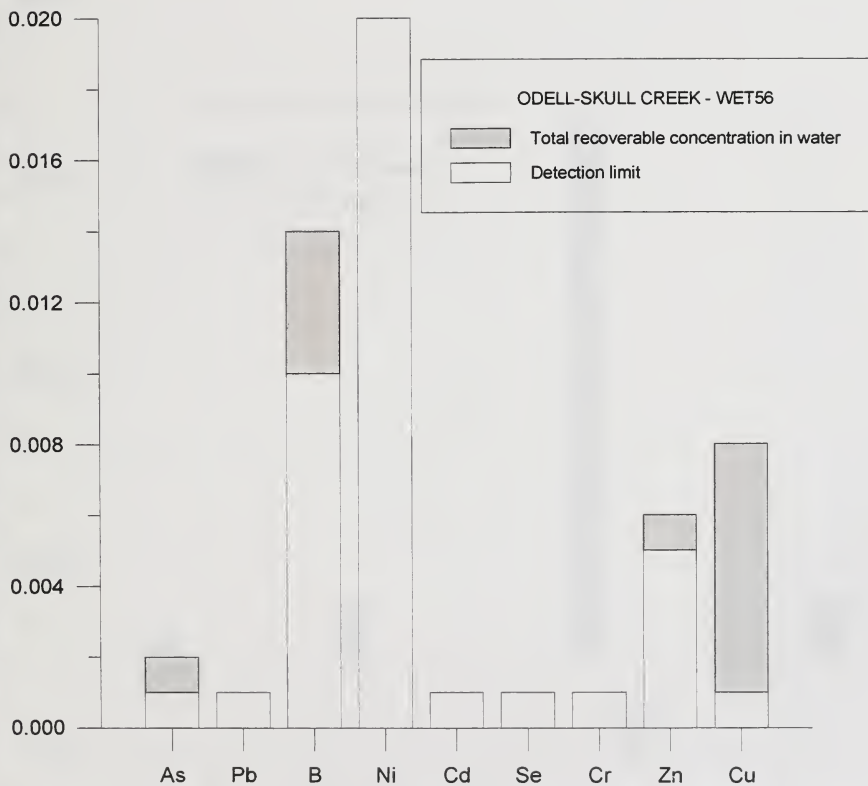
Primary bedrock geologic unit 400MSSL

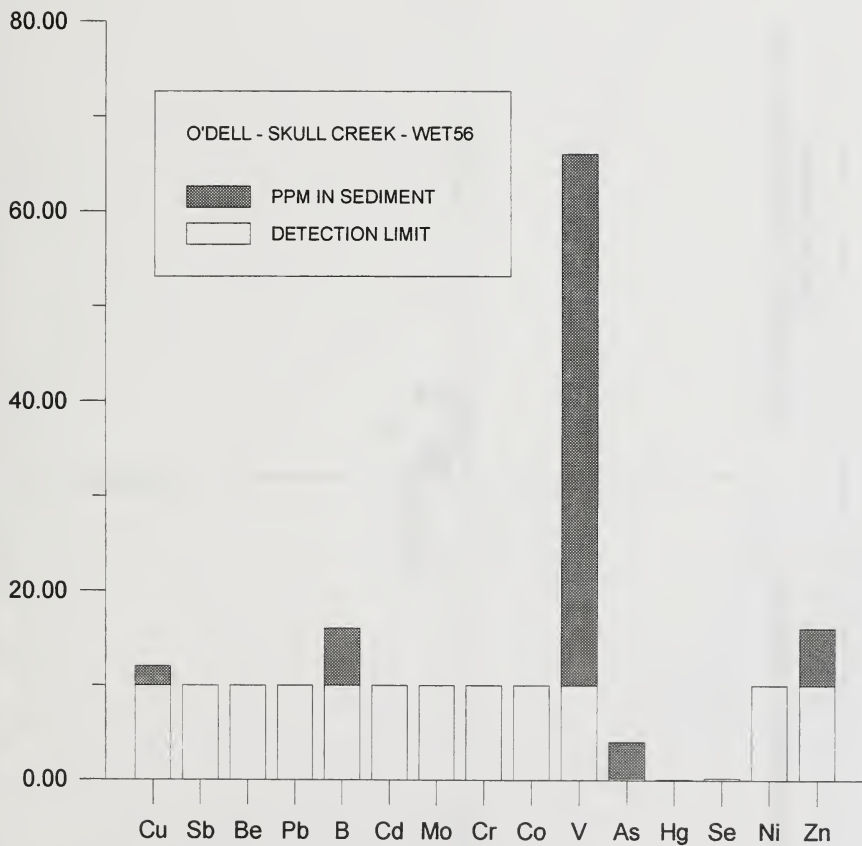
Annual Precipitation in Inches





Concentrations in Milligrams per liter





County Road

County Road

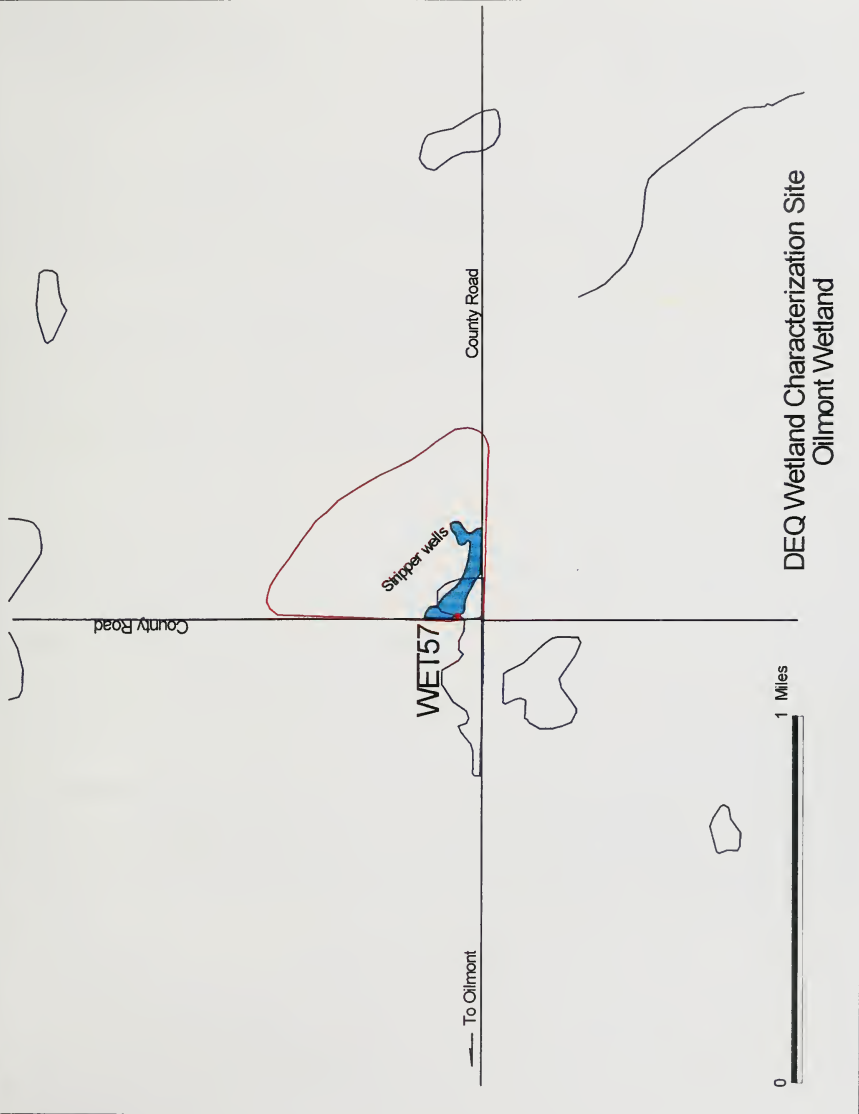
Slipper wells

WET57

— To Oilmont

0 1 Miles

DEQ Wetland Characterization Site
Oilmont Wetland



Wetland: OILMONT WETLAND

Site Code: WET57

7.5 Minute Quad: OILMONT

Lat: 48 44 27

Long: 111 47 45

Mean Annual Precipitation in Inches:	11.00
Mean Annual Potential Evaporation (Penman) in Inches:	38.00
'Net Precipitation' in Inches:	-27.00

Site does not have a mapped surface inlet.

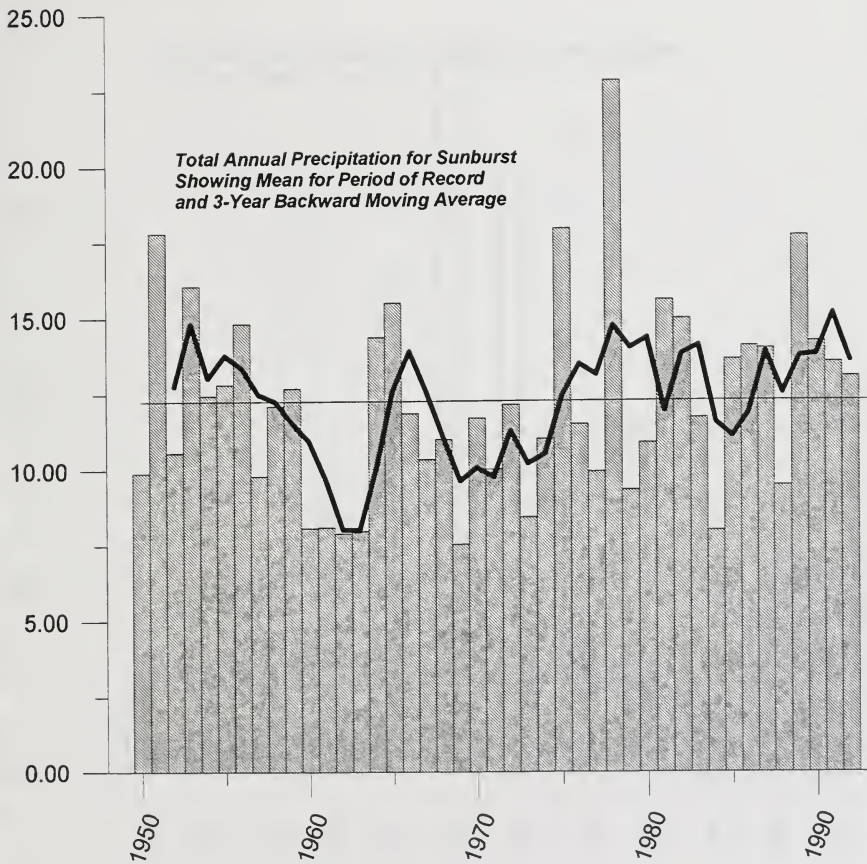
Site does not have a mapped surface outlet.

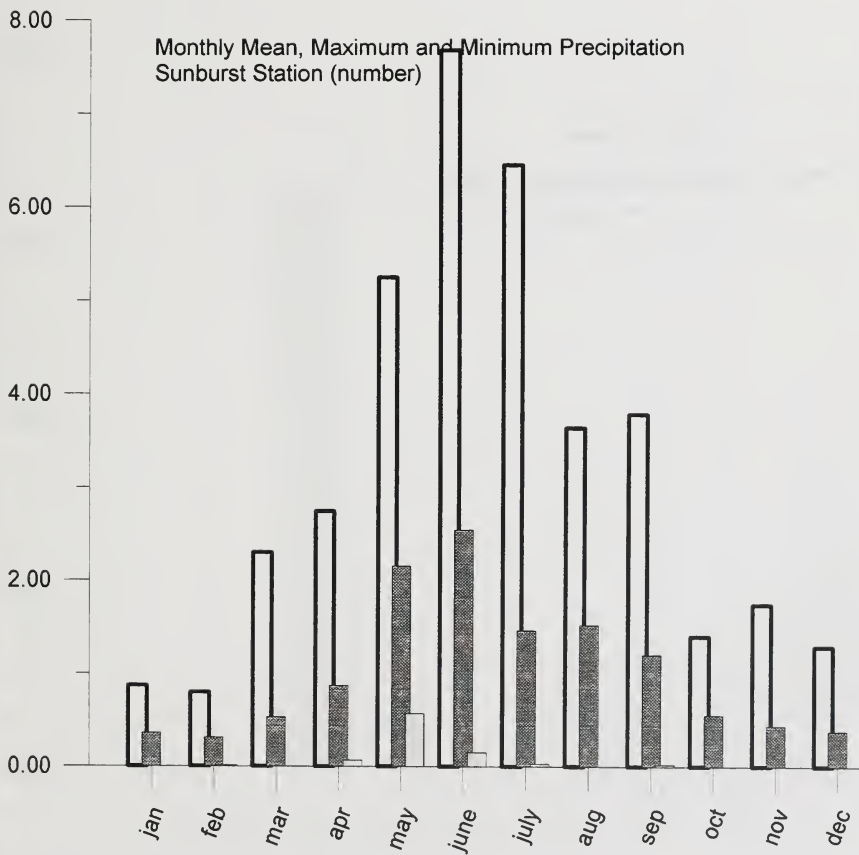
Site is artificially impounded.

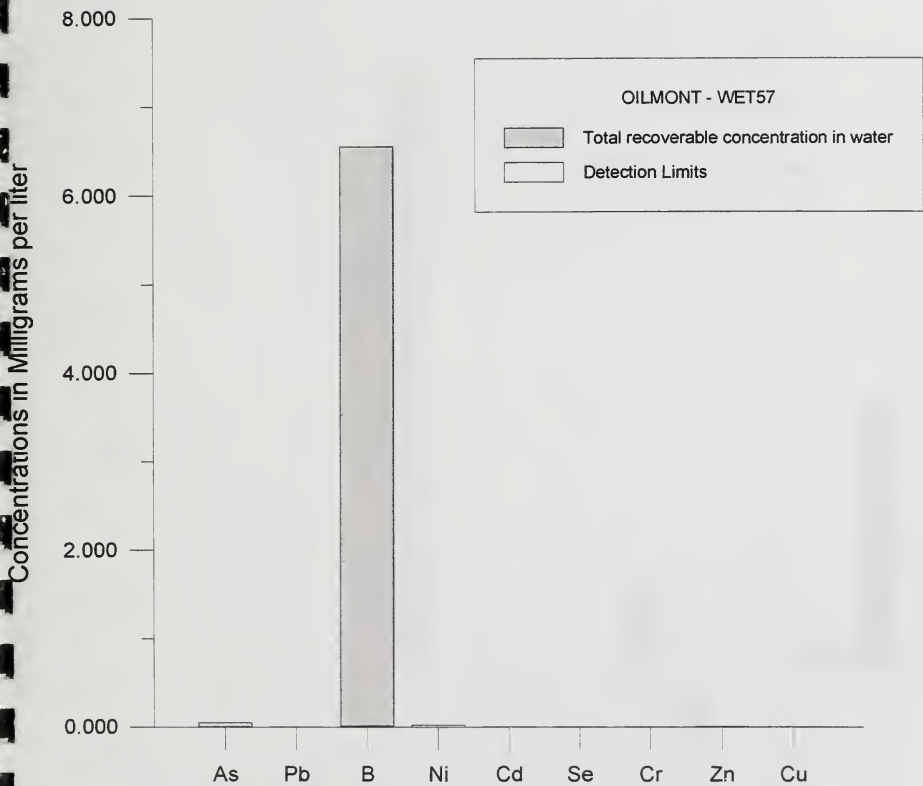
Site does not have known significant water imports.

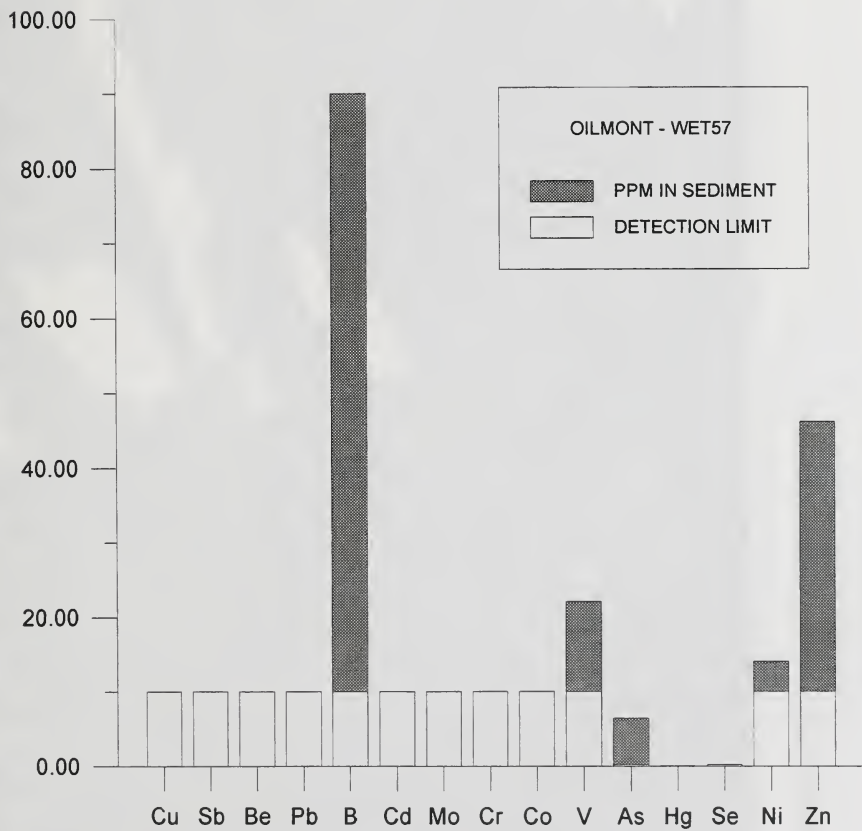
Mapped area of wetland:	9 acres
Area of contributing drainage basin:	140 acres
Mapped elevation of wetland surface:	3445 ft
Maximum elevation within drainage basin:	3505 ft
Net relief of contributing basin:	60 ft
COE Hydrogeomorphic class:	DEPRESSIONAL
Primary surficial geologic unit	112TILL
Primary bedrock geologic unit	211CLRD

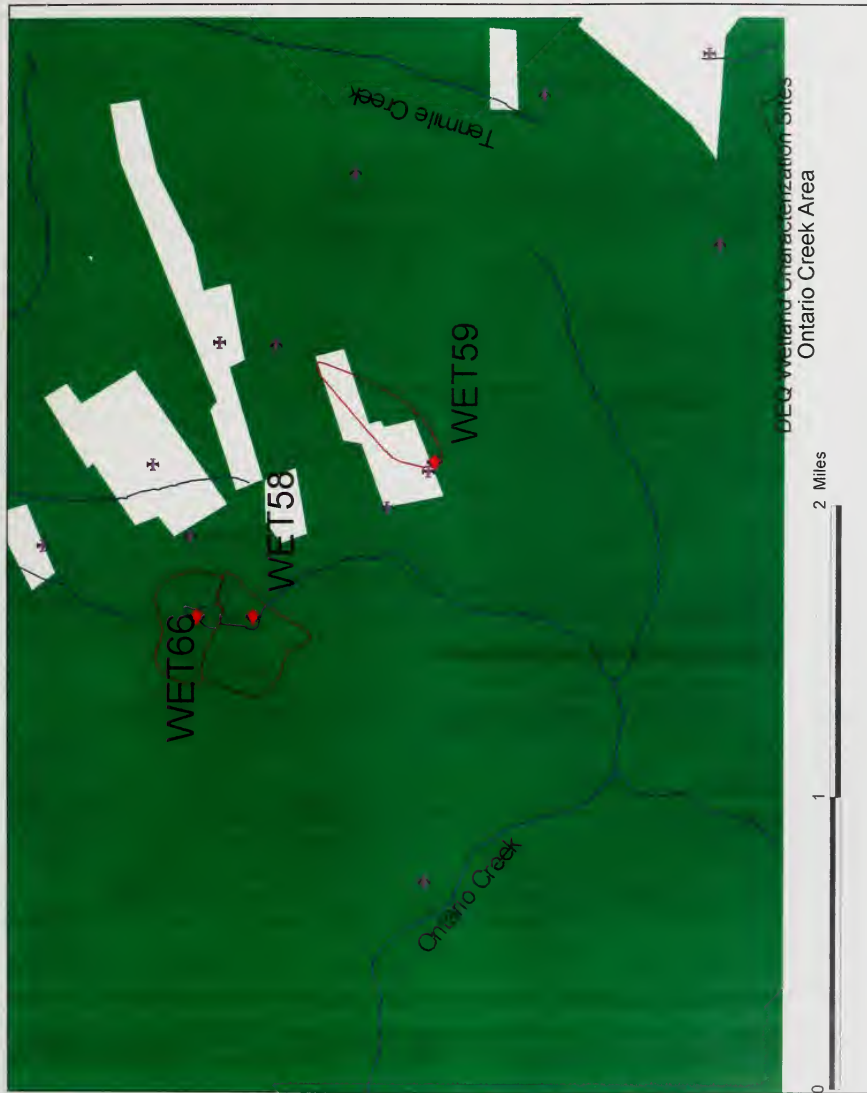
Annual Precipitation in Inches











Wetland: ONTARIO CREEK HEADWATERS

Site Code: WET58

7.5 Minute Quad: THREE BROTHERS

Lat: 46 26 15
Long: 112 21 5

Mean Annual Precipitation in Inches:	25.00
Mean Annual Potential Evaporation (Penman) in Inches:	28.00
'Net Precipitation' in Inches:	-3.00

Site does not have a mapped surface inlet.

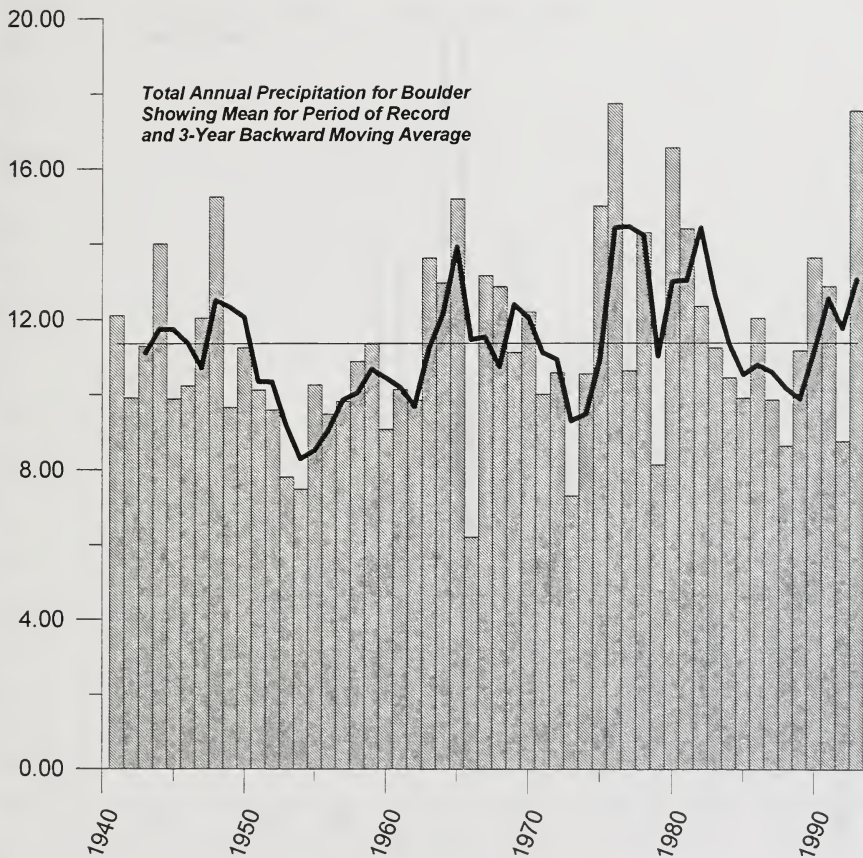
Site has a mapped surface outlet.

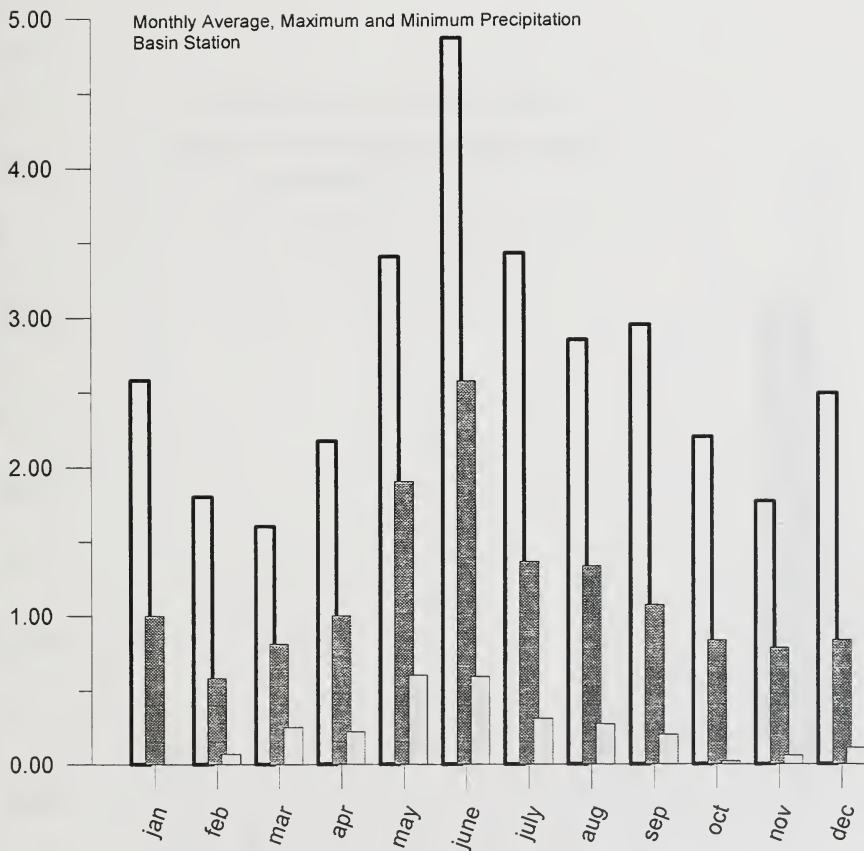
Site is not known to be artificially impounded.

Site does not have known significant water imports.

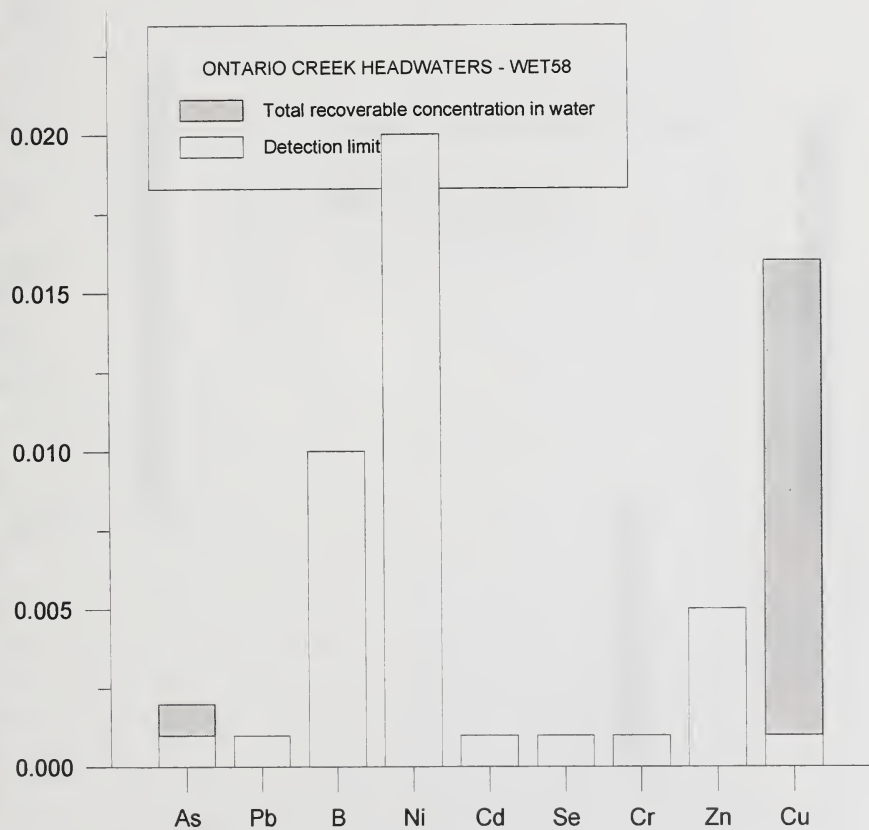
Mapped area of wetland:	5 acres
Area of contributing drainage basin:	56 acres
Mapped elevation of wetland surface:	6970 ft
Maximum elevation within drainage basin:	7125 ft
Net relief of contributing basin:	155 ft

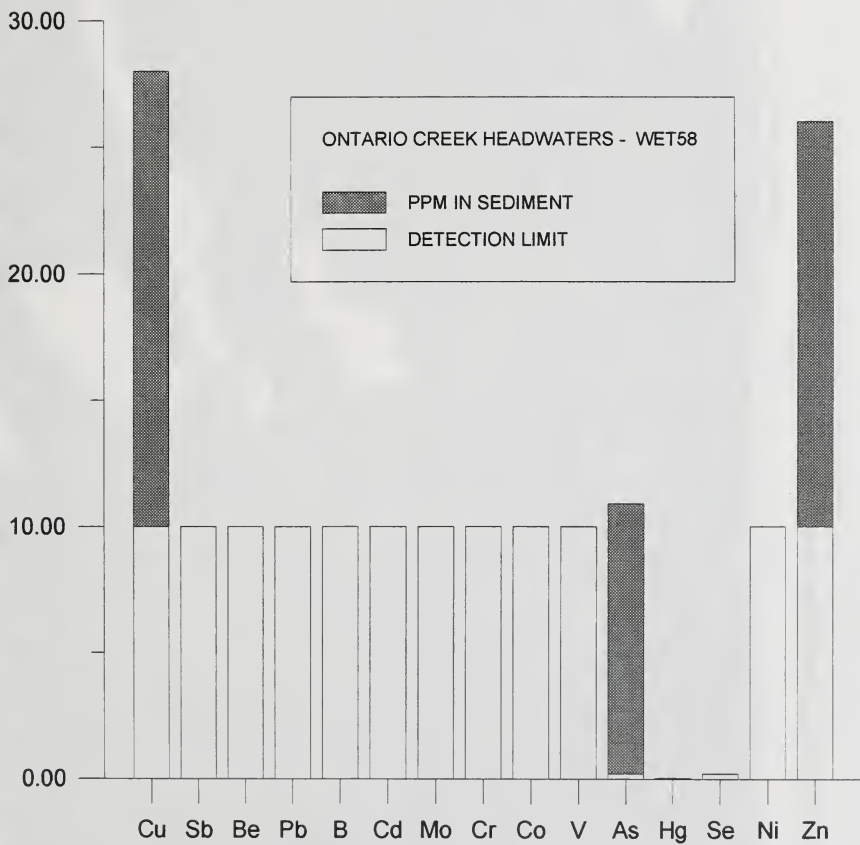
COE Hydrogeomorphic class:	EXTENS PEAT
Primary surficial geologic unit	112TILL
Primary bedrock geologic unit	211ELKM

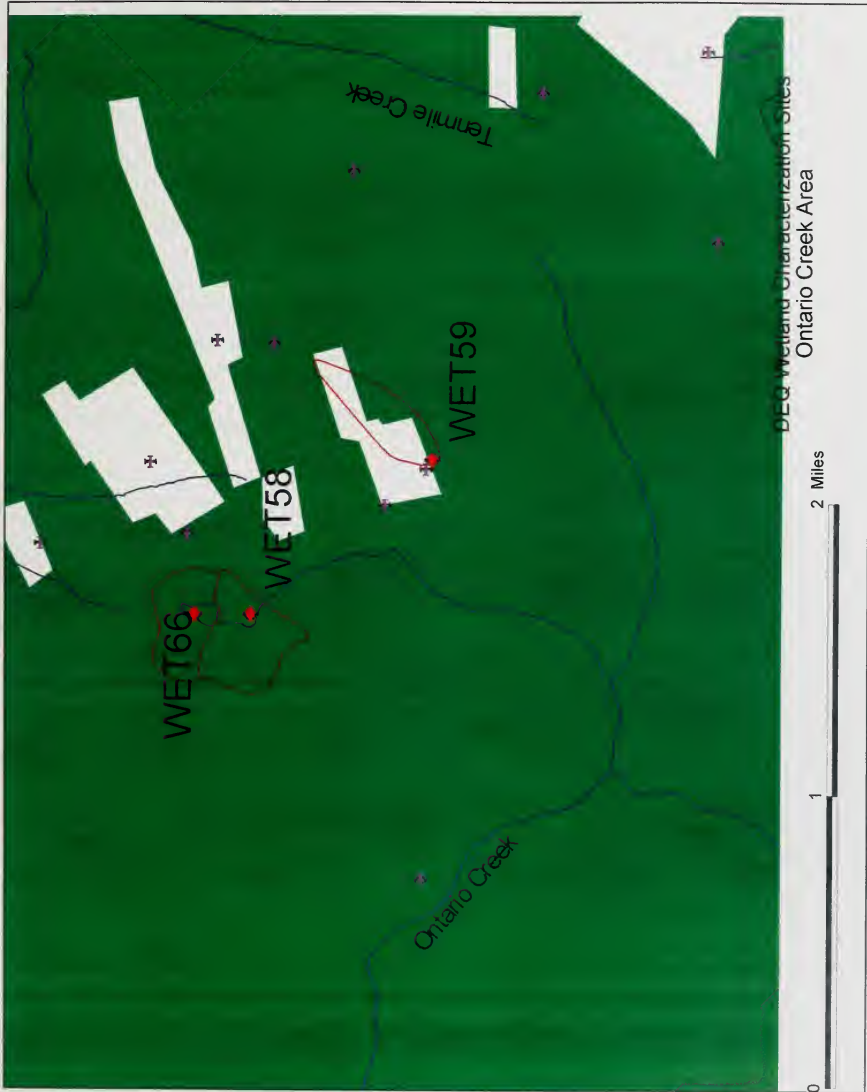




Concentrations in Milligrams per liter







Wetland: ONTARIO MINE WETLAND
7.5 Minute Quad: THREE BROTHERS

Site Code: WET59

Lat: 46 25 45
Long: 112 20 20

Mean Annual Precipitation in Inches: 25.00
Mean Annual Potential Evaporation (Penman) in Inches: 28.00
'Net Precipitation' in Inches: -3.00

Site has a mapped surface inlet.

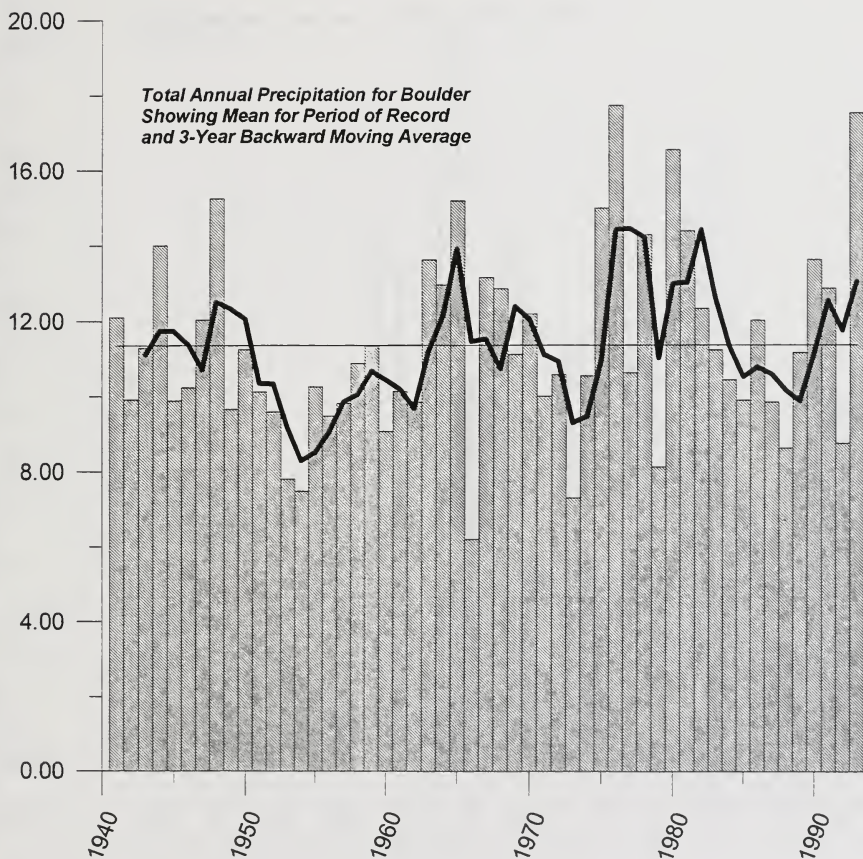
Site has a mapped surface outlet.

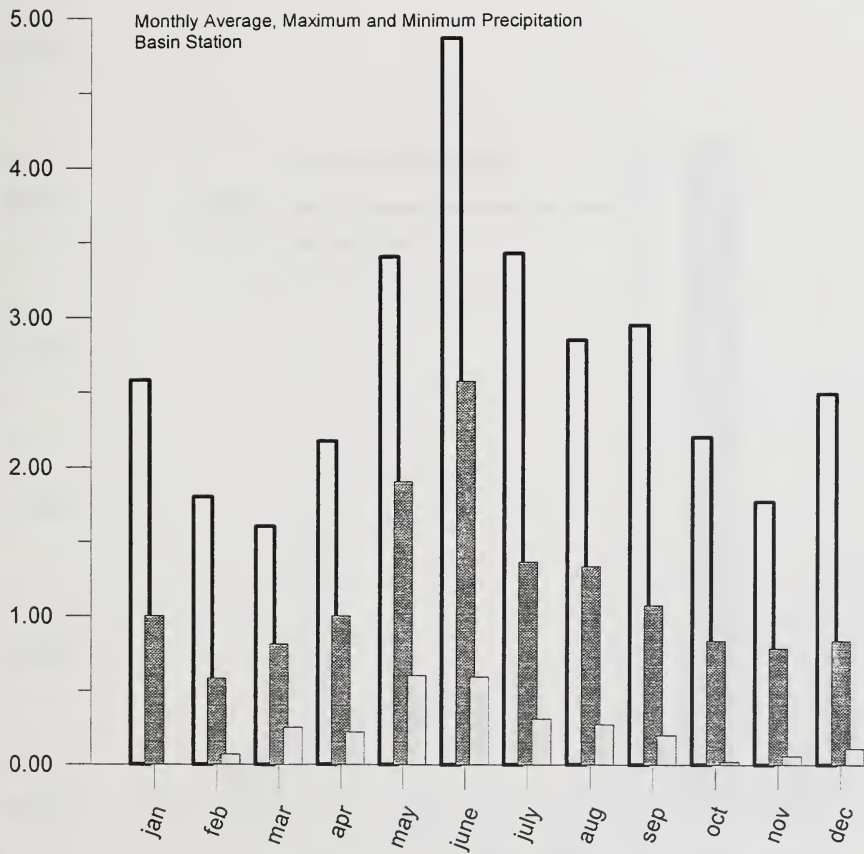
Site is not known to be artificially impounded.

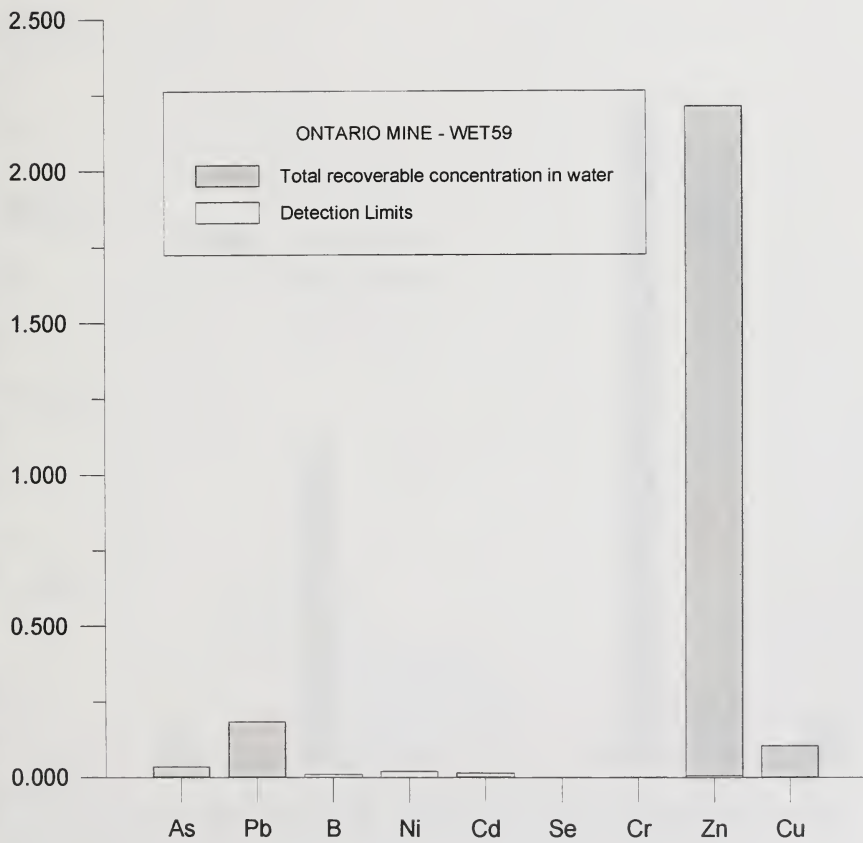
Site does not have known significant water imports.

Mapped area of wetland: 20 acres
Area of contributing drainage basin: 40 acres
Mapped elevation of wetland surface: 6960 ft
Maximum elevation within drainage basin: 7530 ft
Net relief of contributing basin: 570 ft

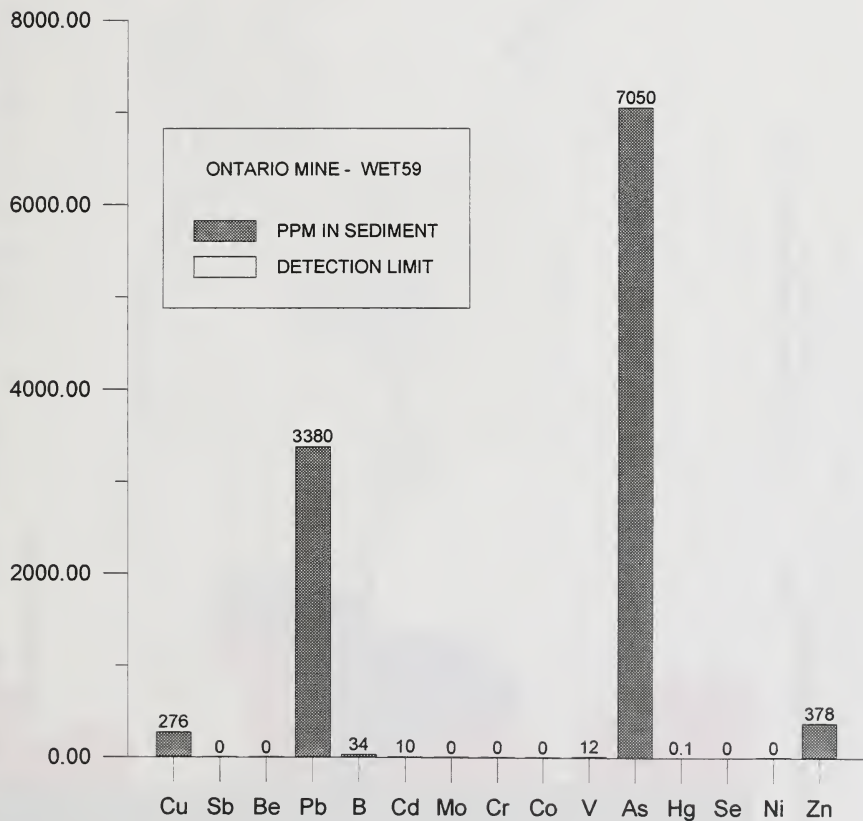
COE Hydrogeomorphic class: RIVERINE
Primary surficial geologic unit
Primary bedrock geologic unit 210CRCS

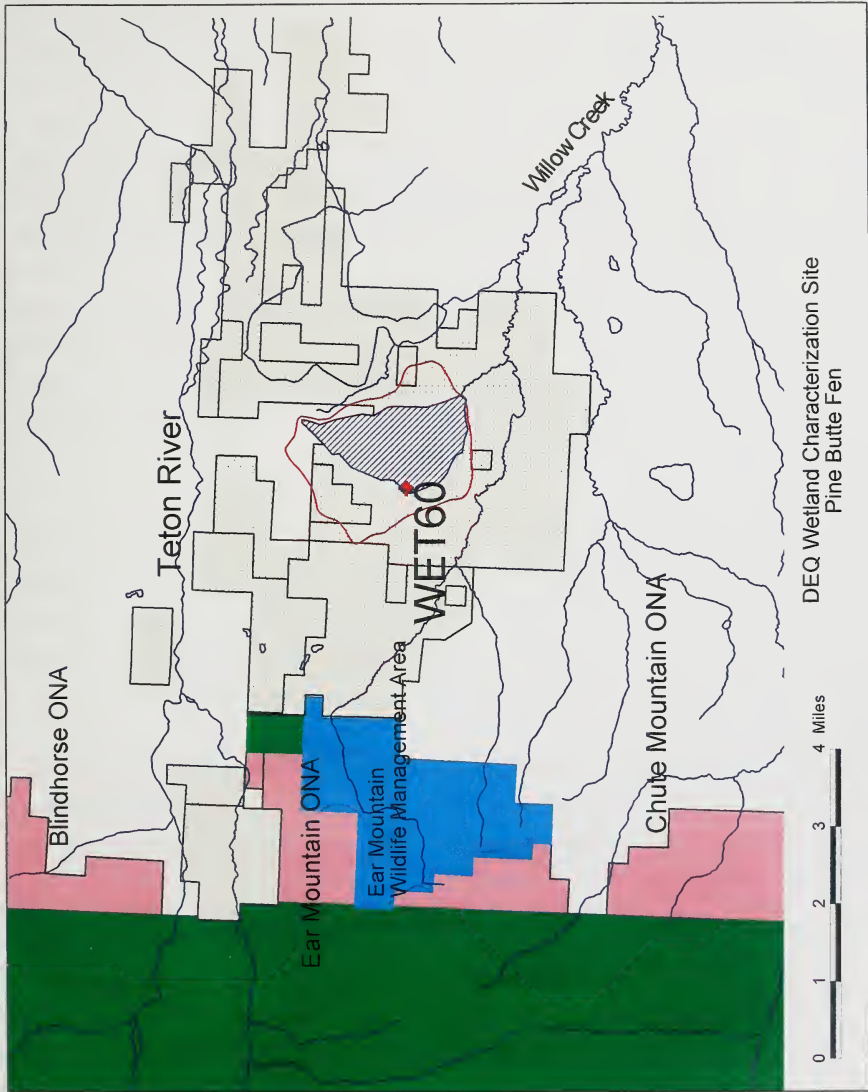






HNO3 - Extractable Sediment Concentrations in PPM





Wetland: PINE BUTTE FEN

Site Code: WET60

7.5 Minute Quad: LAKE THEBOE

Lat: 47 50 35

Long: 112 35 25

Mean Annual Precipitation in Inches:	17.00
Mean Annual Potential Evaporation (Penman) in Inches:	37.00
'Net Precipitation' in Inches:	-20.00

Site does not have a mapped surface inlet.

Site has a mapped surface outlet.

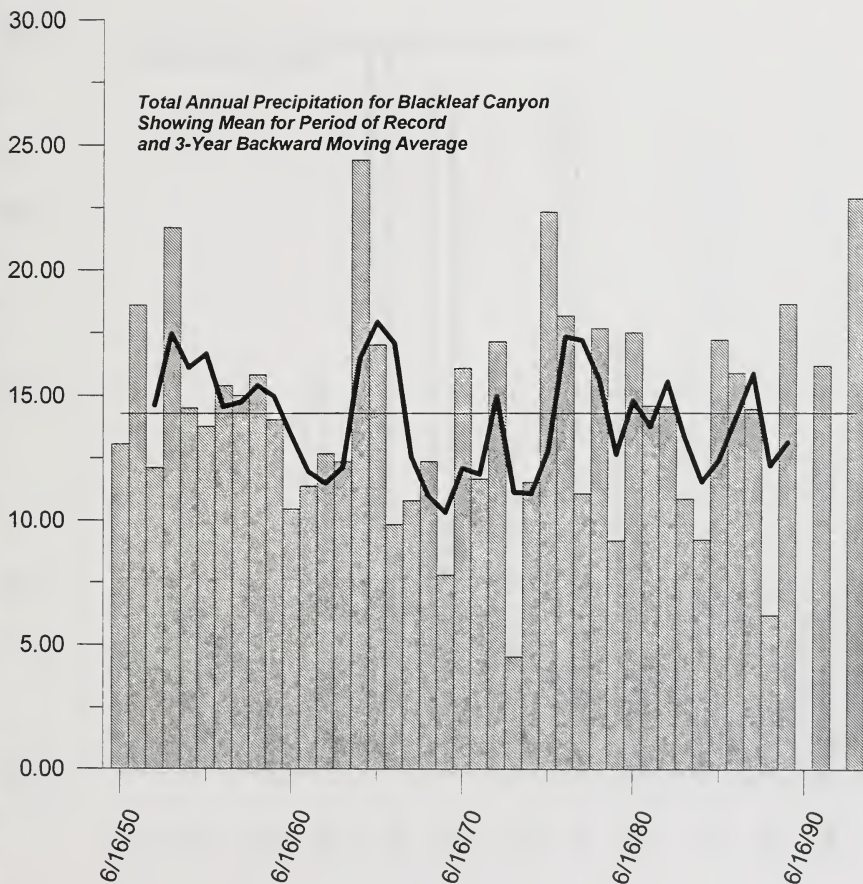
Site is not known to be artificially impounded.

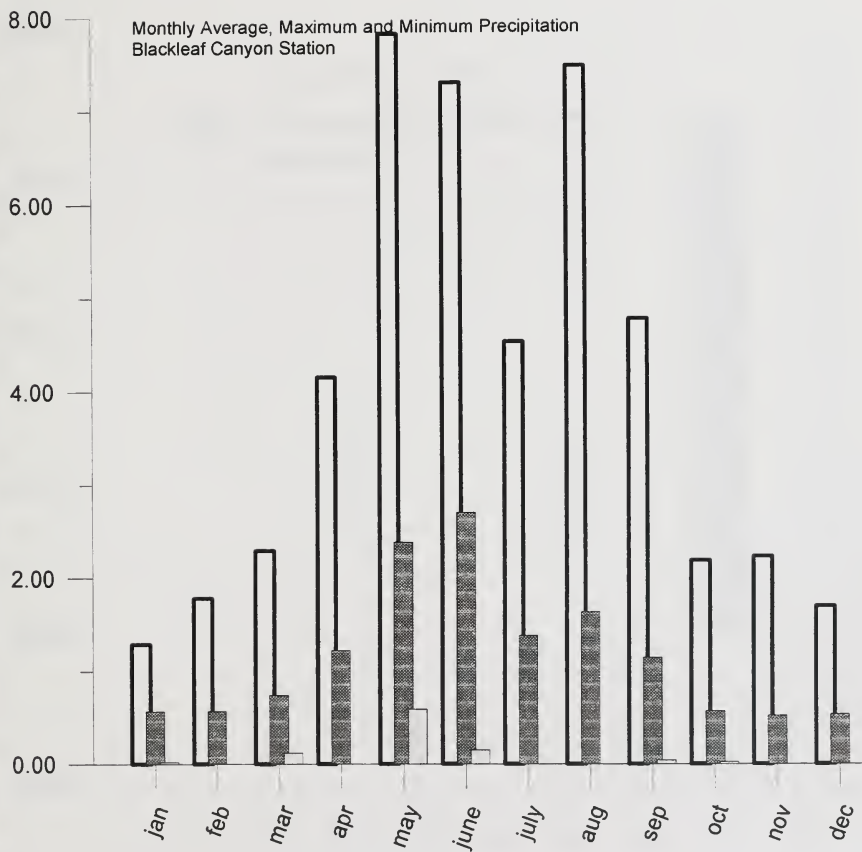
Site does not have known significant water imports.

Mapped area of wetland:	980 acres
Area of contributing drainage basin:	2230 acres
Mapped elevation of wetland surface:	4610 ft
Maximum elevation within drainage basin:	5012 ft
Net relief of contributing basin:	402 ft

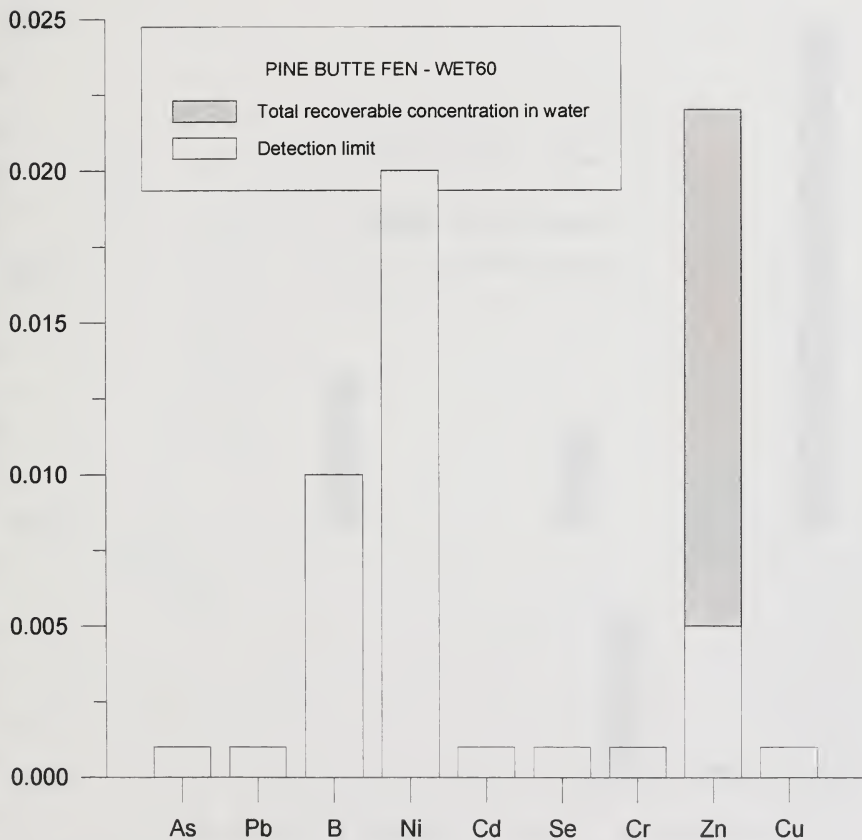
COE Hydrogeomorphic class:	EXTENS PEAT
Primary surficial geologic unit	112OTSH
Primary bedrock geologic unit	211MNTN

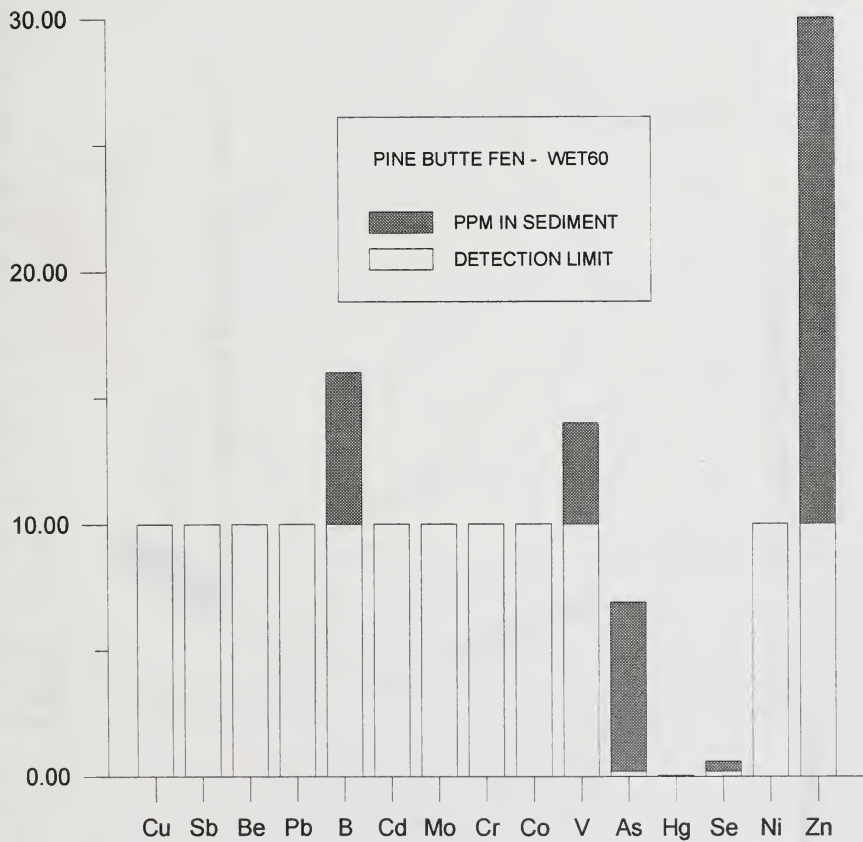
Annual Precipitation in Inches

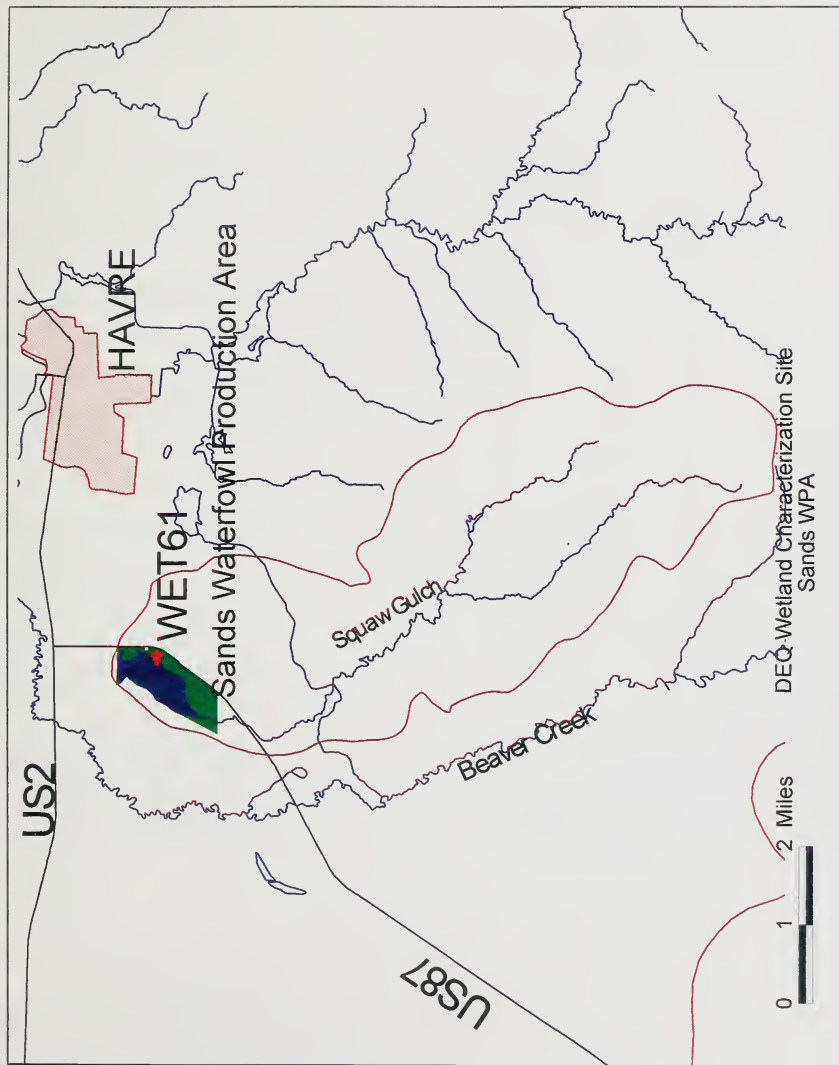




Concentrations in Milligrams per liter







Wetland: SANDS WPA

Site Code: WET61

7.5 Minute Quad: HAVRE

Lat: 48 32 20

Long: 109 44 50

Mean Annual Precipitation in Inches: 11.00

Mean Annual Potential Evaporation (Penman) in Inches: 38.00

'Net Precipitation' in Inches: -27.00

Site has a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site has significant water imports.

Mapped area of wetland: 240 acres

Area of contributing drainage basin: 12810 acres

Mapped elevation of wetland surface: 2570 ft

Maximum elevation within drainage basin: 3050 ft

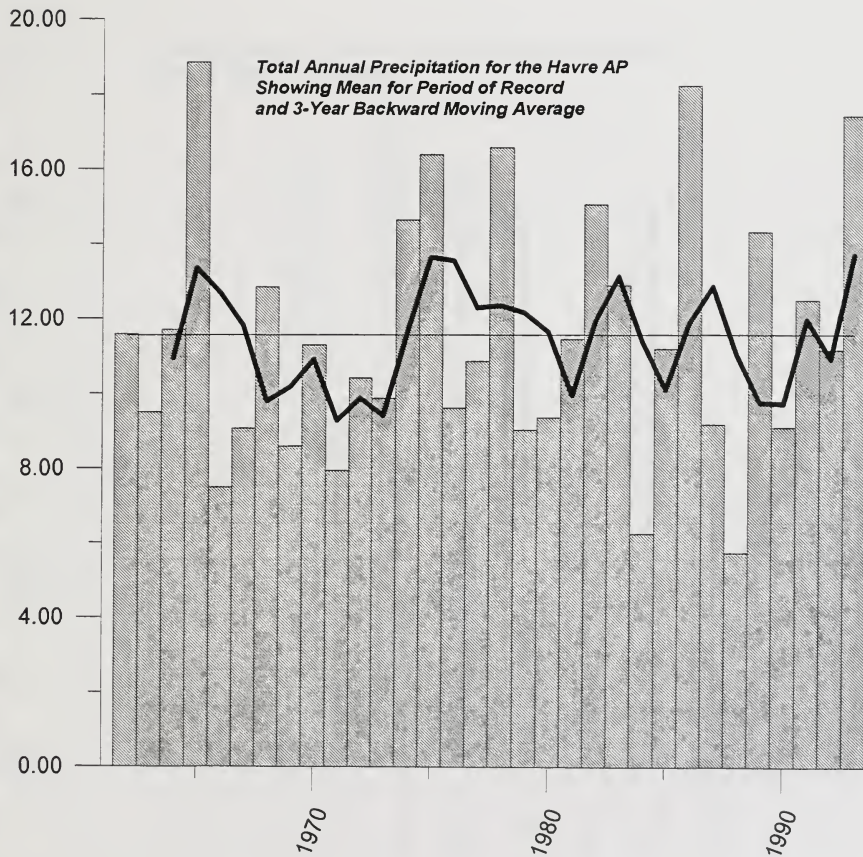
Net relief of contributing basin: 480 ft

COE Hydrogeomorphic class: DEPRESSIONAL

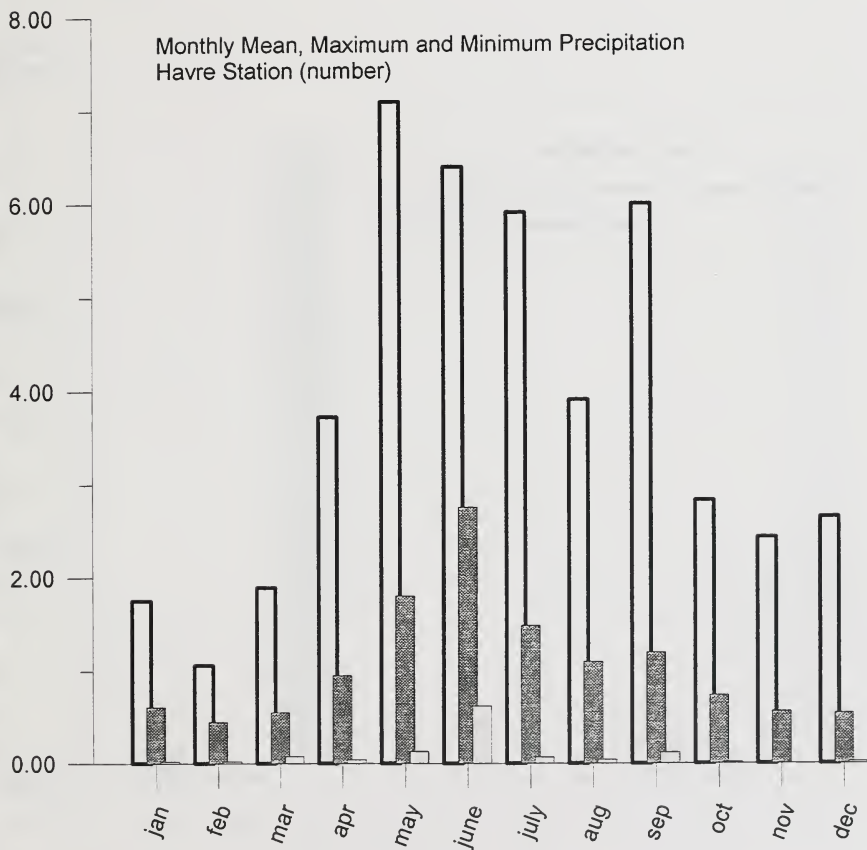
Primary surficial geologic unit 112DRFT

Primary bedrock geologic unit 211JDRV

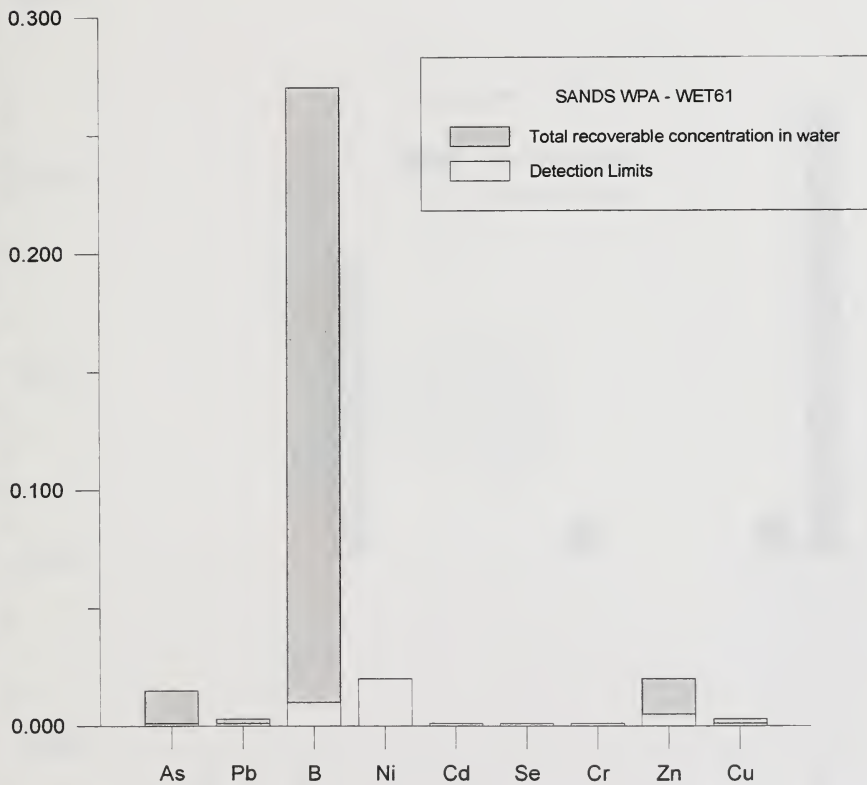
Annual Precipitation in Inches

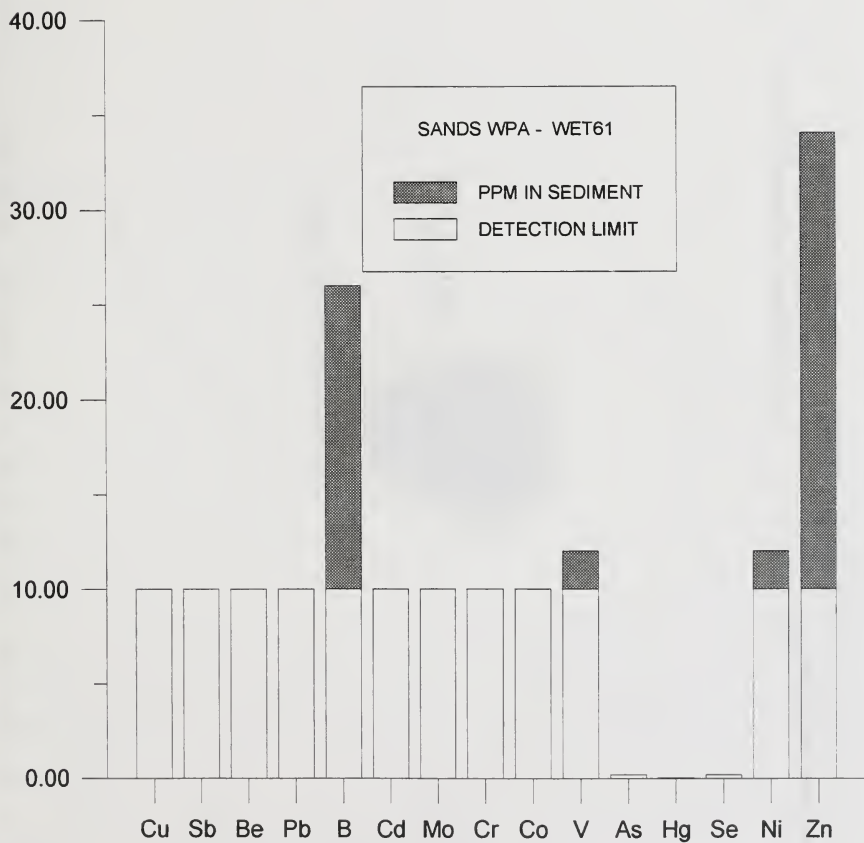


Inches Precipitation



Concentrations in Milligrams per liter



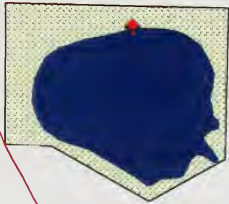


Schrammeck Lake WPA

WET62

DEQ Wetland Characterization Site
Schrammeck Lake WPA

0 1 Miles



Wetland: SCHRAMMECK LAKE WPA
7.5 Minute Quad: SCHRAMMECK LAKE

Site Code: WET62

Lat: 47 14 20
Long: 111 31 40

Mean Annual Precipitation in Inches:	15.00
Mean Annual Potential Evaporation (Penman) in Inches:	40.00
'Net Precipitation' in Inches:	-25.00

Site has a mapped surface inlet.

Site does not have a mapped surface outlet.

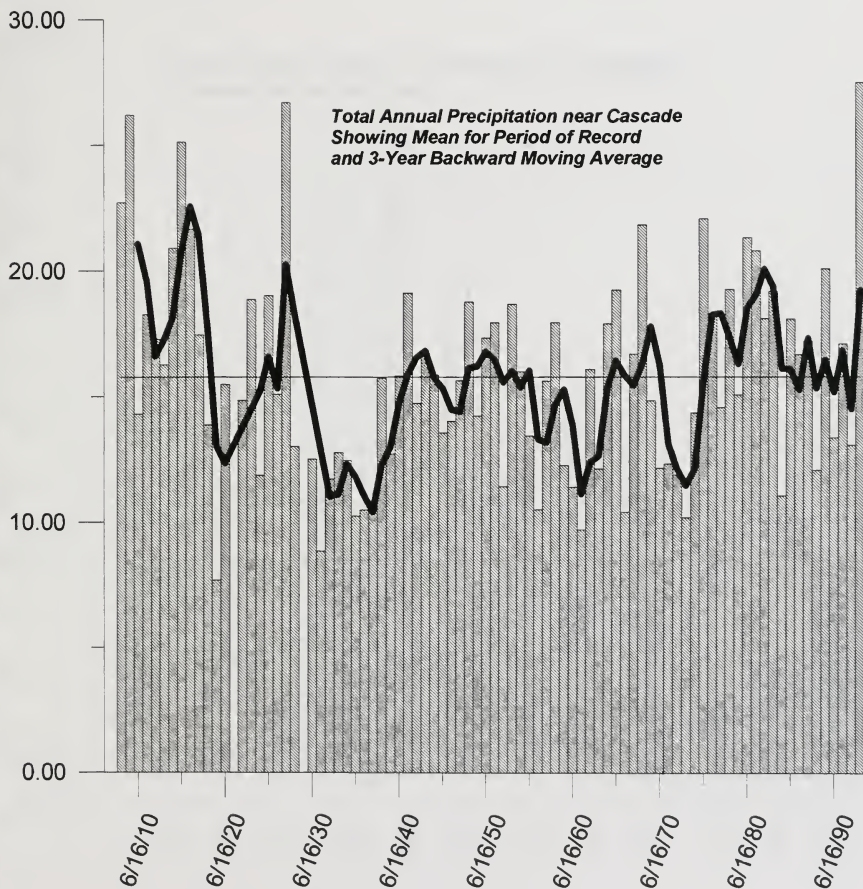
Site is not known to be artificially impounded.

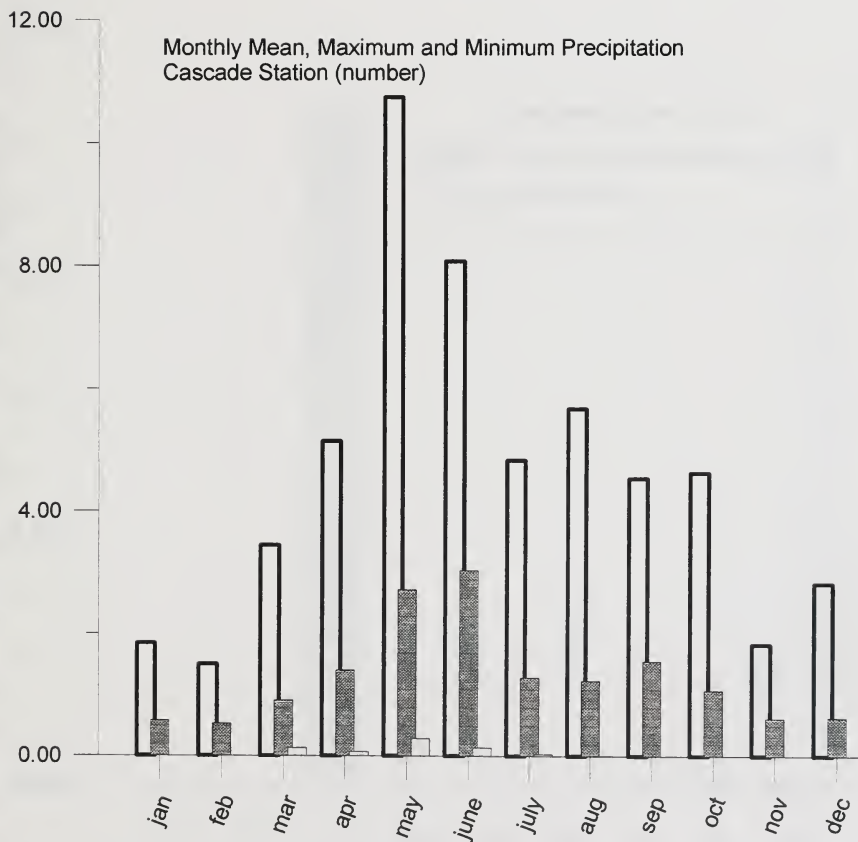
Site does not have known significant water imports.

Mapped area of wetland:	205 acres
Area of contributing drainage basin:	1450 acres
Mapped elevation of wetland surface:	3735 ft
Maximum elevation within drainage basin:	3930 ft
Net relief of contributing basin:	195 ft

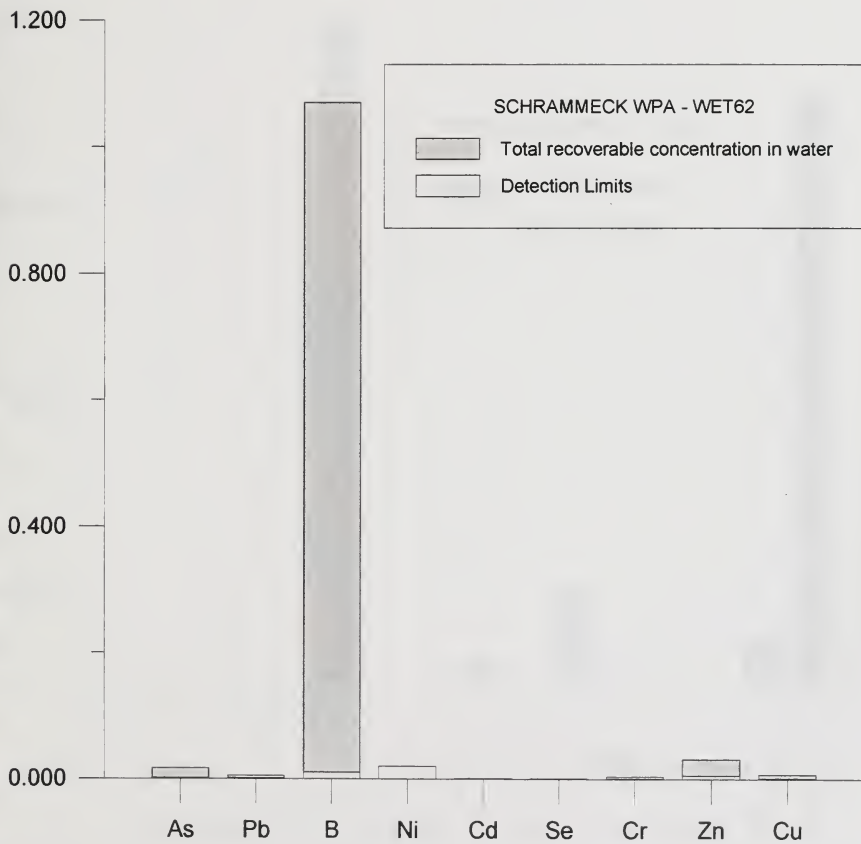
COE Hydrogeomorphic class:	FRINGE
Primary surficial geologic unit	110"LAC"
Primary bedrock geologic unit	211CLR

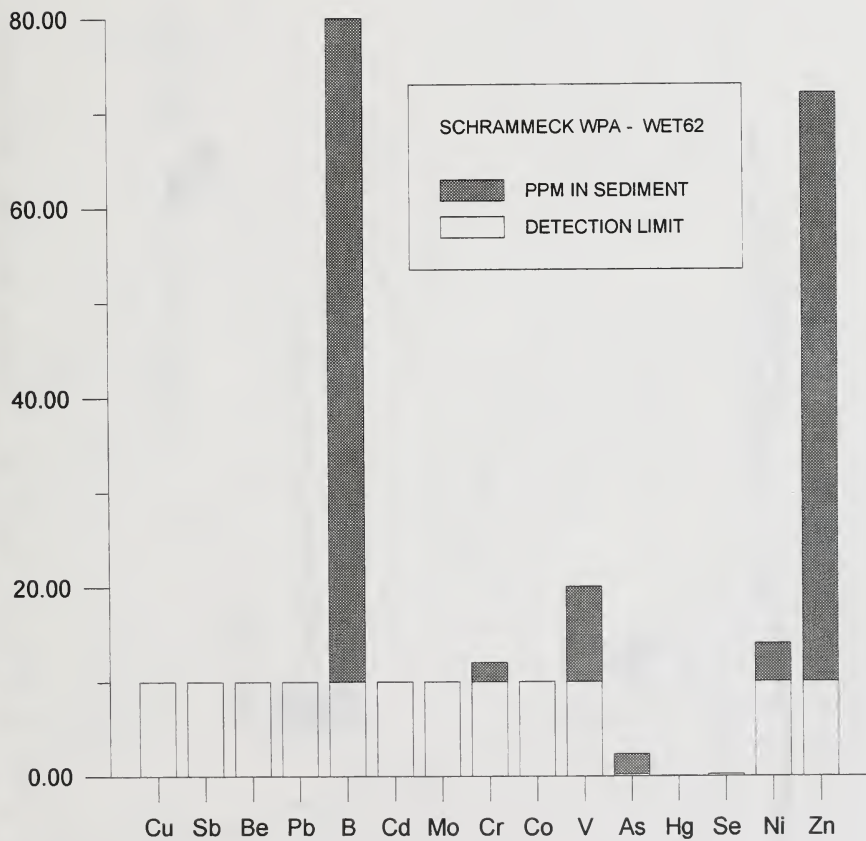
Annual Precipitation in Inches

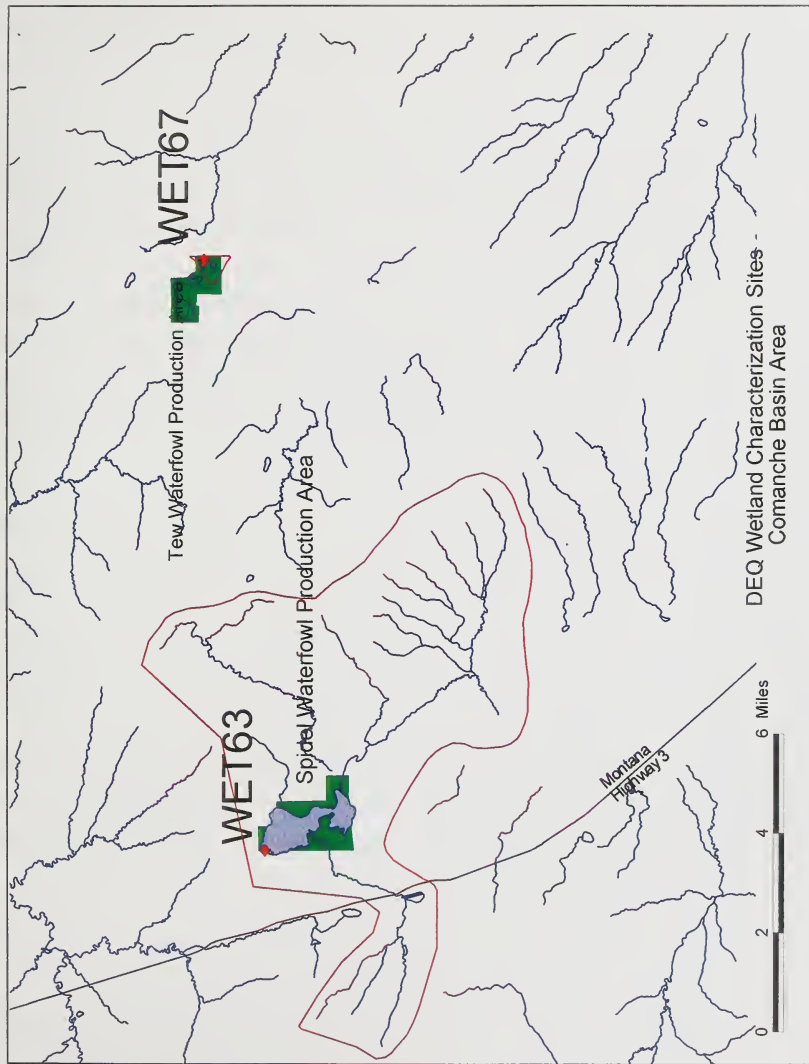




Concentrations in Milligrams per liter







Wetland: SPIDEL WPA

Site Code: WET63

7.5 Minute Quad: BROADVIEW NORTHEAST

Lat: 46 9 0
Long: 108 51 40

Mean Annual Precipitation in Inches:	13.00
Mean Annual Potential Evaporation (Penman) in Inches:	42.00
'Net Precipitation' in Inches:	-29.00

Site has a mapped surface inlet.

Site does not have a mapped surface outlet.

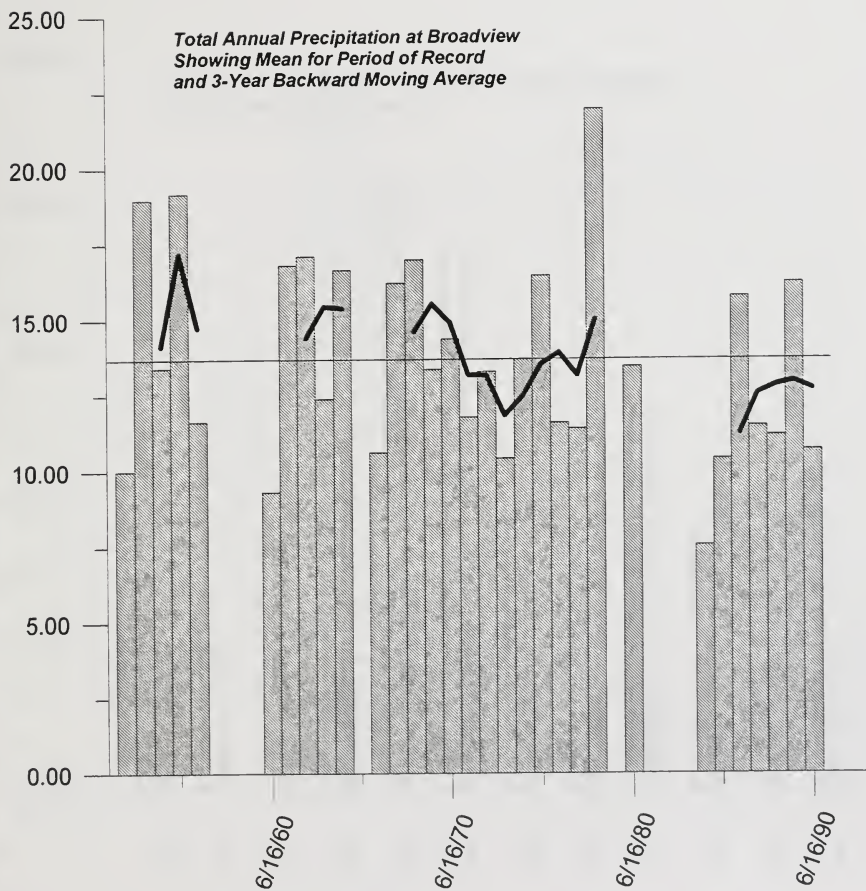
Site is not known to be artificially impounded.

Site does not have known significant water imports.

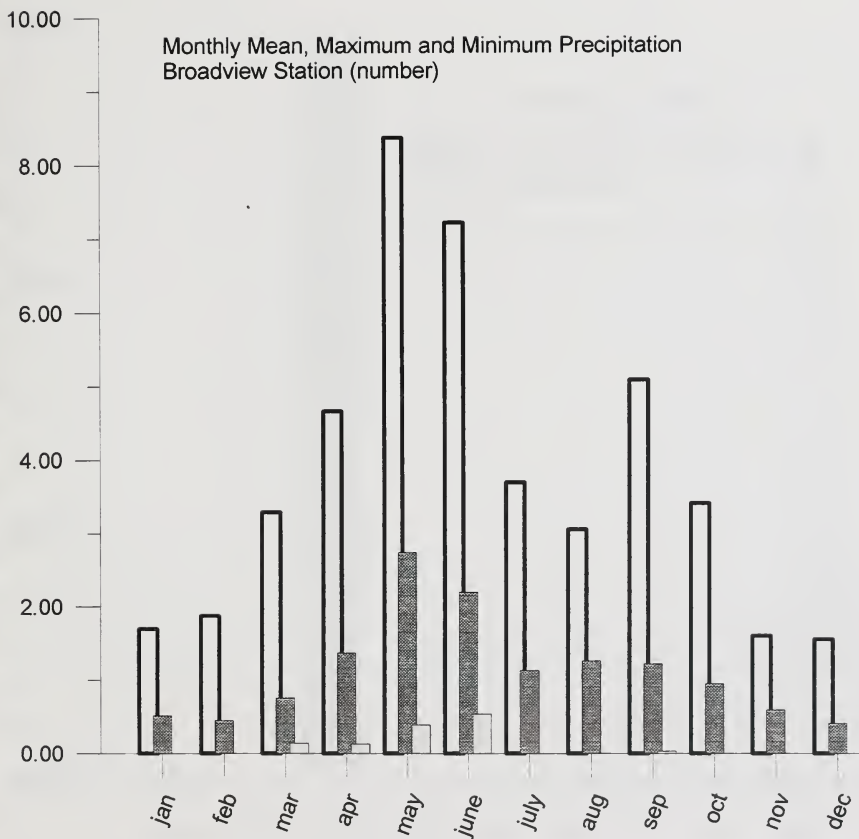
Mapped area of wetland:	675 acres
Area of contributing drainage basin:	27430 acres
Mapped elevation of wetland surface:	3796 ft
Maximum elevation within drainage basin:	4231 ft
Net relief of contributing basin:	435 ft

COE Hydrogeomorphic class:	DEPRESSIONAL
Primary surficial geologic unit	110"LAC"
Primary bedrock geologic unit	211LNCE

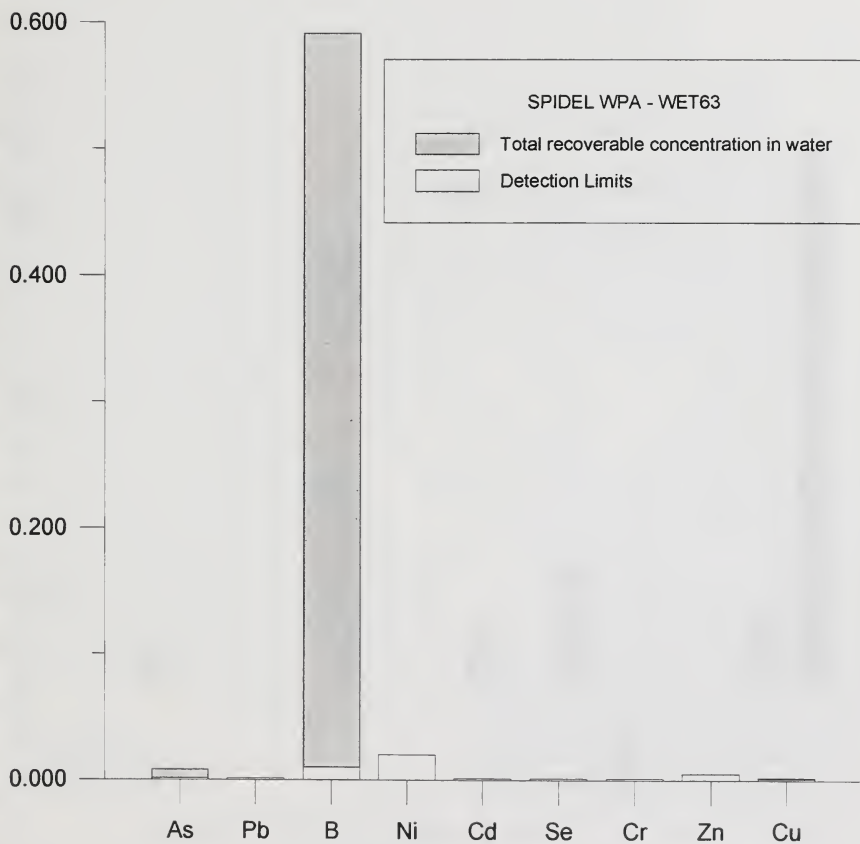
Annual Precipitation in Inches

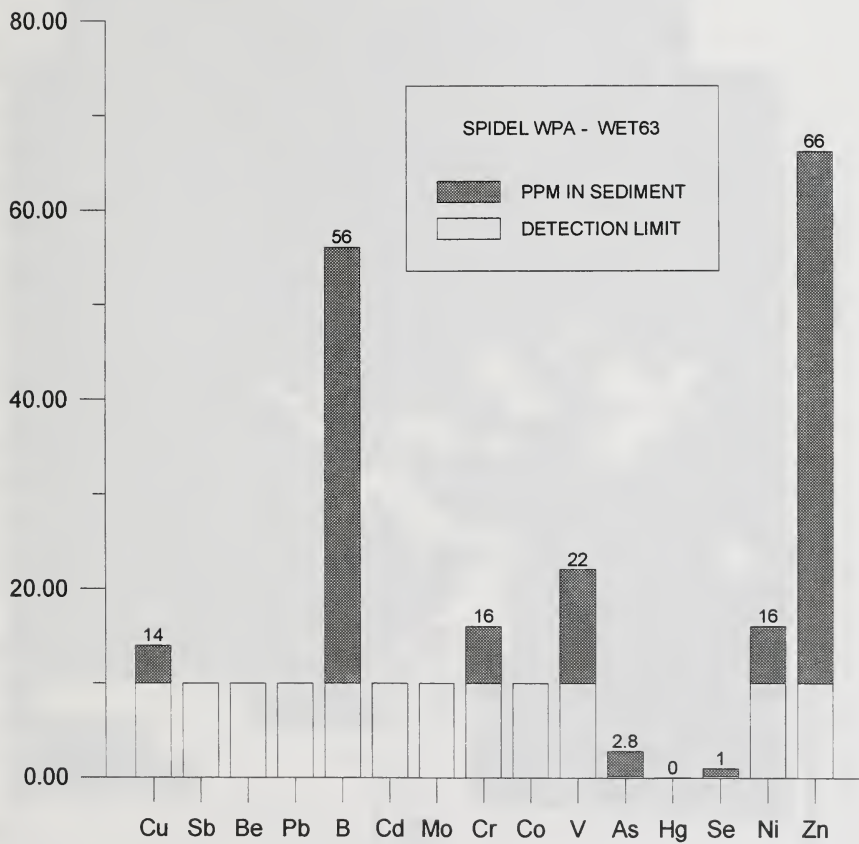


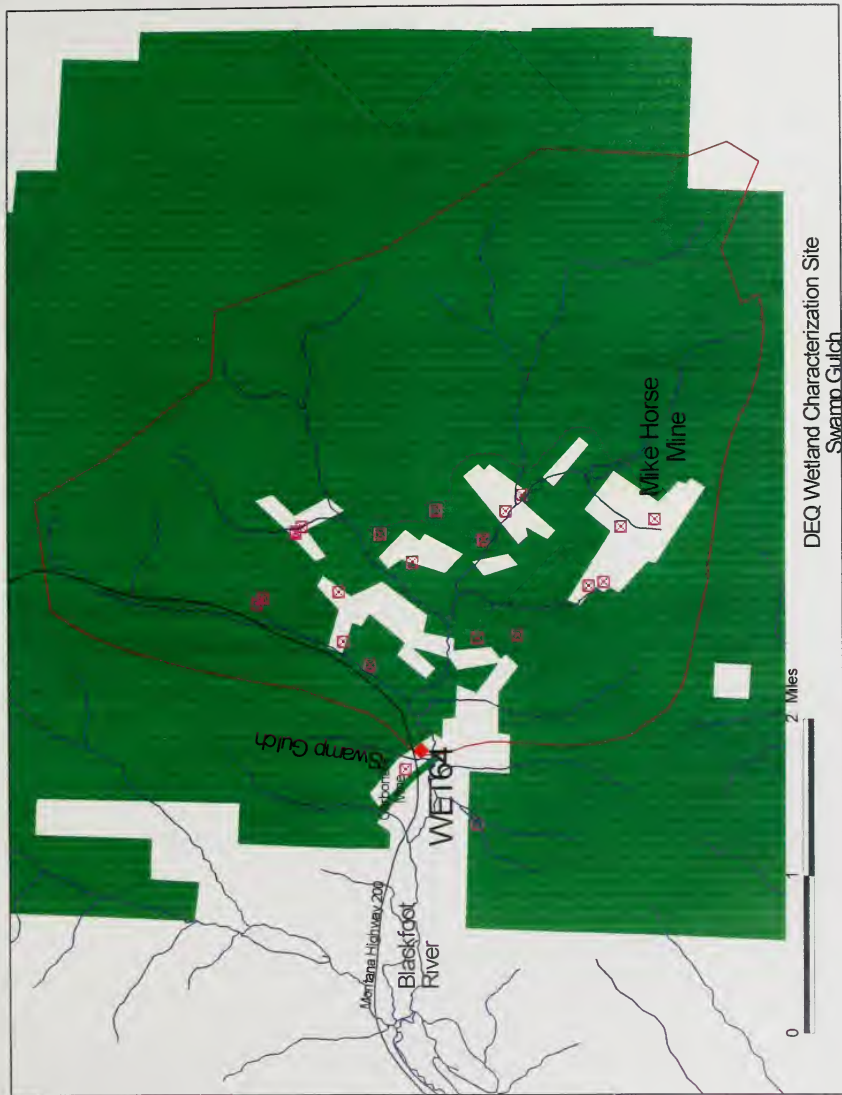
Monthly Mean, Maximum and Minimum Precipitation
Broadview Station (number)



Concentrations in Milligrams per liter







Wetland: SWAMP GULCH WETLAND
7.5 Minute Quad: CADOTTE CREEK

Site Code: WET64

Lat: 47 2 35
Long: 112 23 35

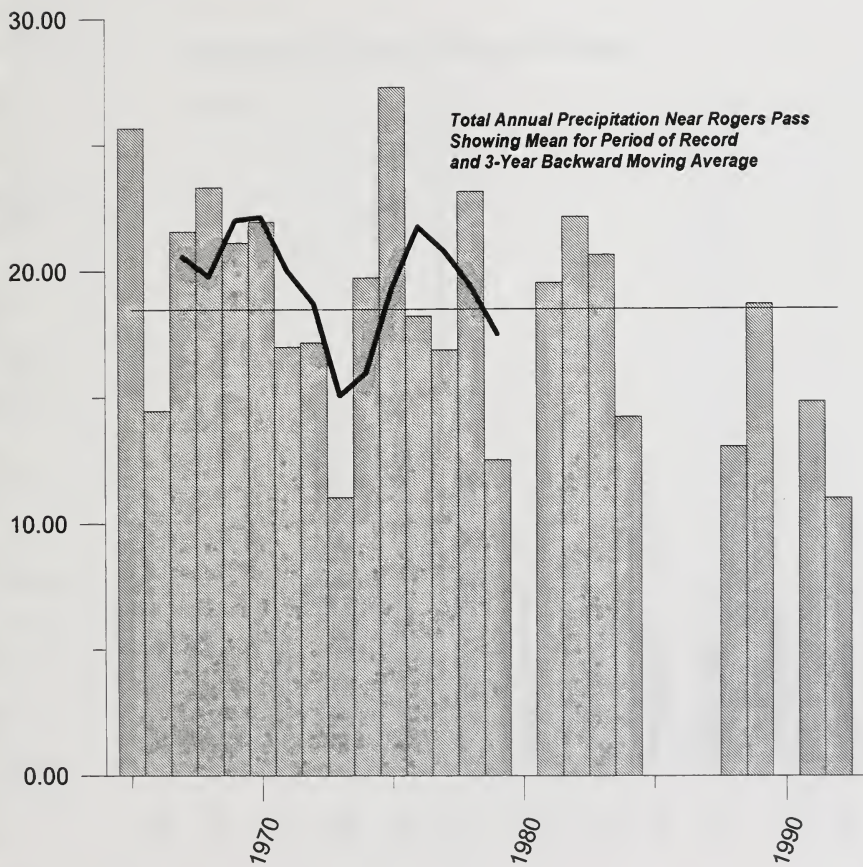
Mean Annual Precipitation in Inches: 25.00
Mean Annual Potential Evaporation (Penman) in Inches: 29.00
'Net Precipitation' in Inches: -4.00

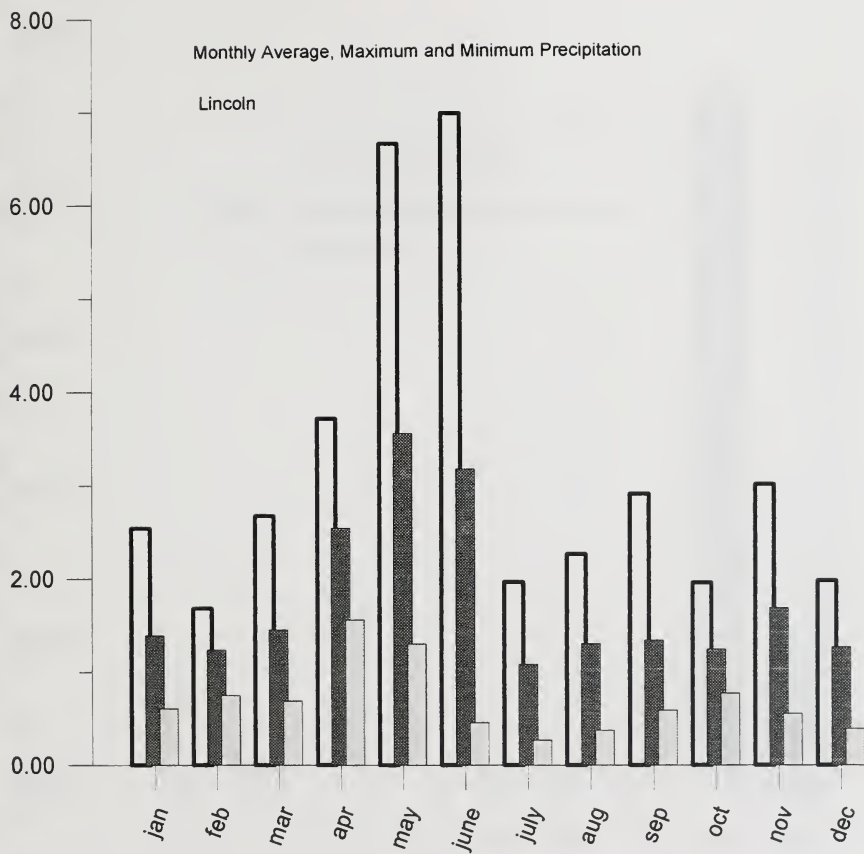
Site has a mapped surface inlet.
Site has a mapped surface outlet.
Site is not known to be artificially impounded.
Site does not have known significant water imports.

Mapped area of wetland: 115 acres
Area of contributing drainage basin: 7680 acres
Mapped elevation of wetland surface: 5165 ft
Maximum elevation within drainage basin: 7497 ft
Net relief of contributing basin: 2332 ft

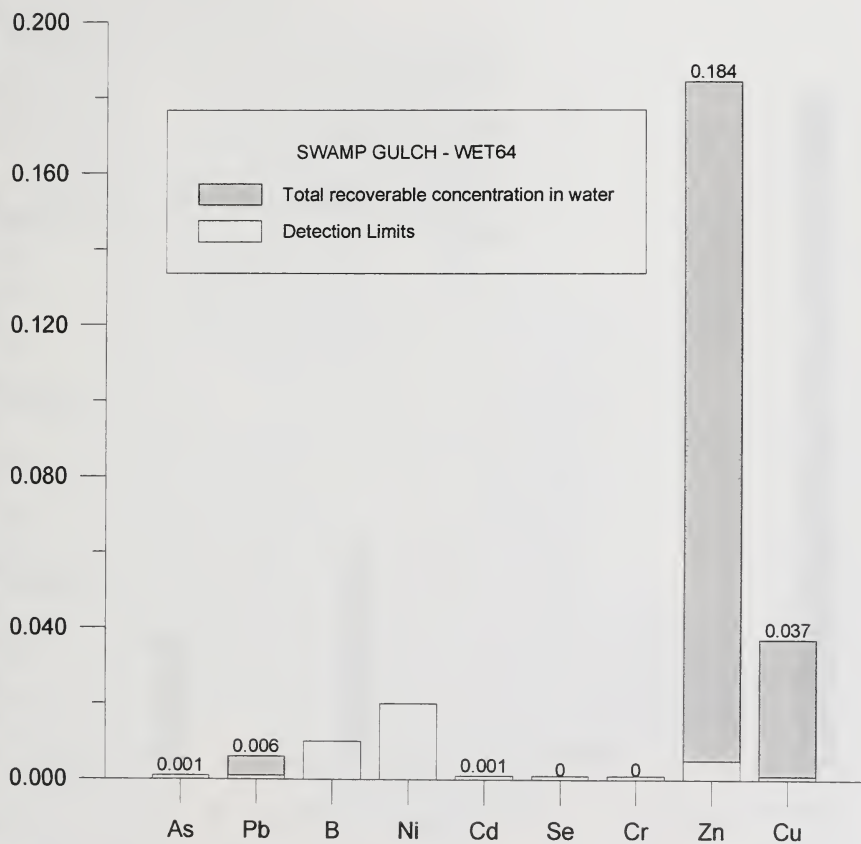
COE Hydrogeomorphic class: RIVERINE
Primary surficial geologic unit 110ALVM
Primary bedrock geologic unit 400BELT

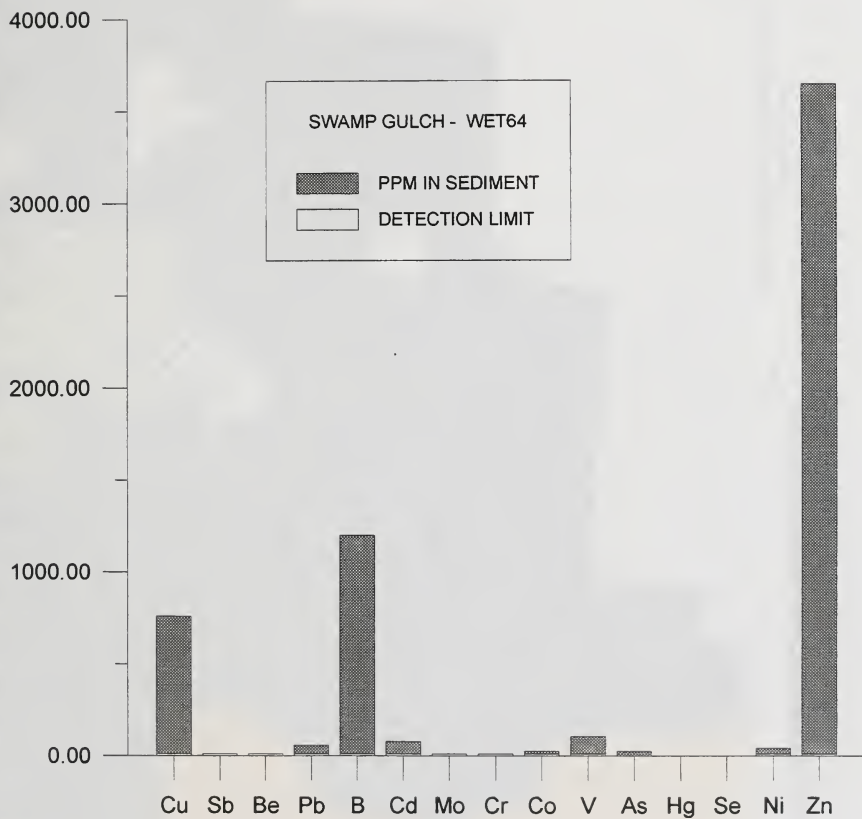
Annual Precipitation in Inches





Concentrations in Milligrams per liter





Flathead Indian Reservation

Swan River National Wildlife Refuge

WET65

Montana Highway 83

DEQ Wetland Characterization Site
Swan River

0 2 4 Miles

0

2

4

Miles

Wetland: SWAN RIVER PROPOSED RNA

Site Code: WET65

7.5 Minute Quad: CILLY CREEK

Lat: 47 51 50

Long: 113 52 2

Mean Annual Precipitation in Inches: 25.00

Mean Annual Potential Evaporation (Penman) in Inches: 33.00

'Net Precipitation' in Inches: -8.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 40 acres

Area of contributing drainage basin: 2800 acres

Mapped elevation of wetland surface: 3095 ft

Maximum elevation within drainage basin: 5285 ft

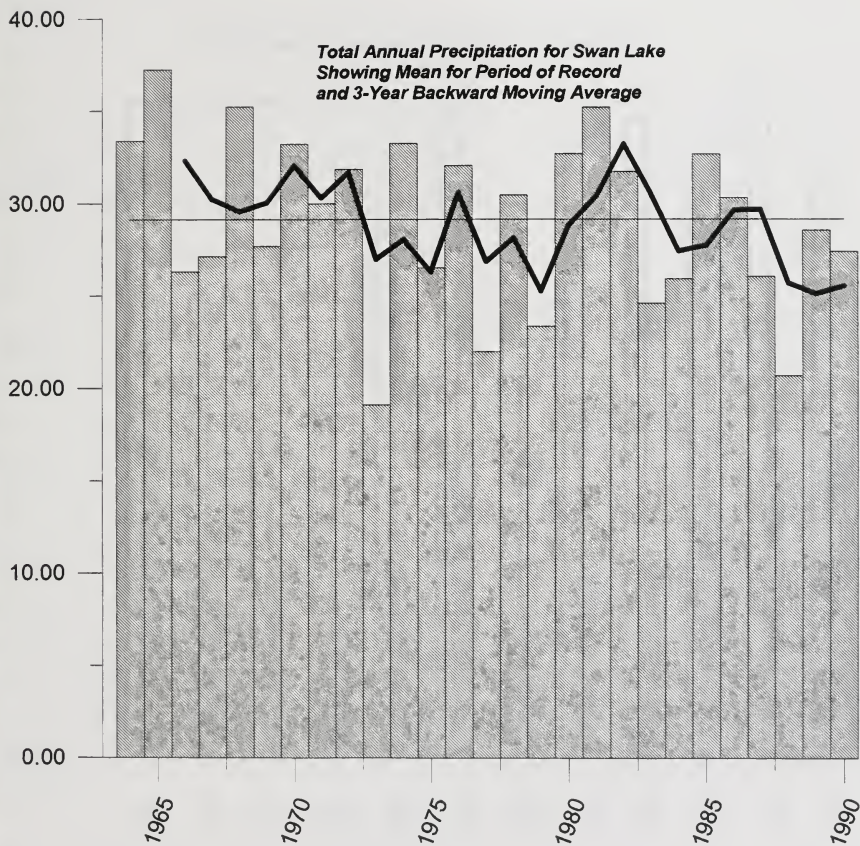
Net relief of contributing basin: 2190 ft

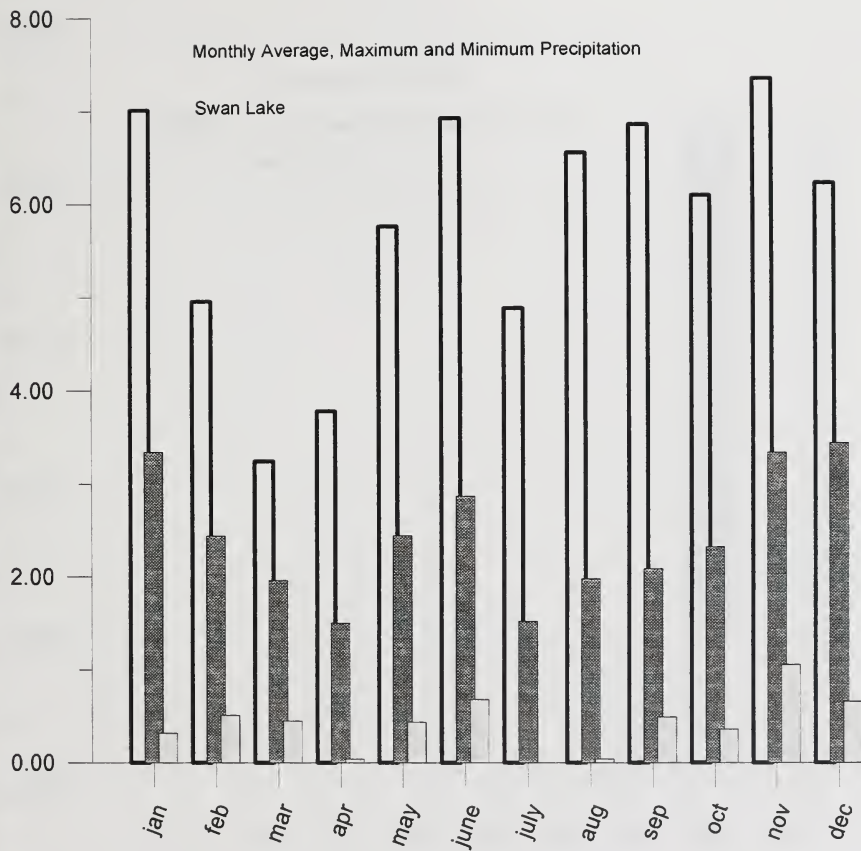
COE Hydrogeomorphic class: RIVERINE

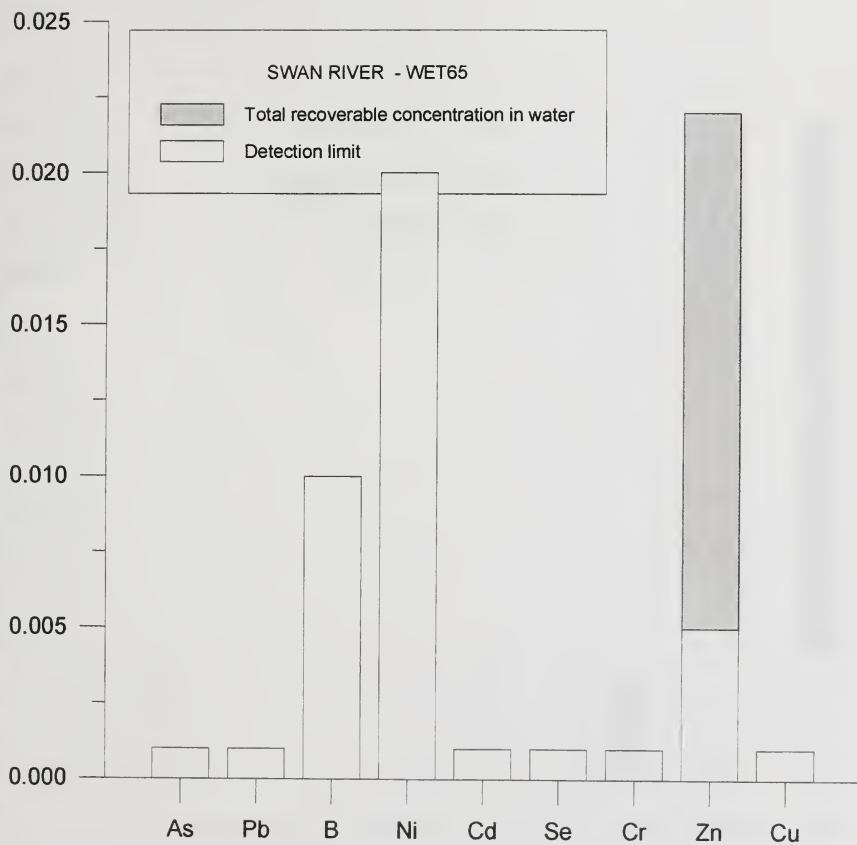
Primary surficial geologic unit 111ALVM

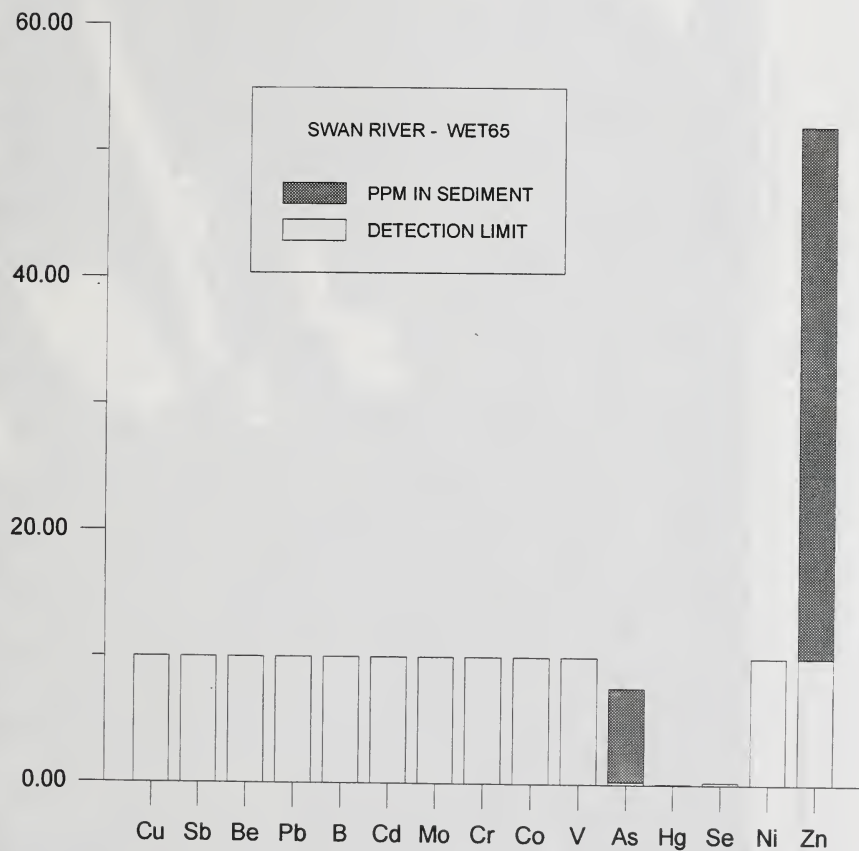
Primary bedrock geologic unit 400HELN

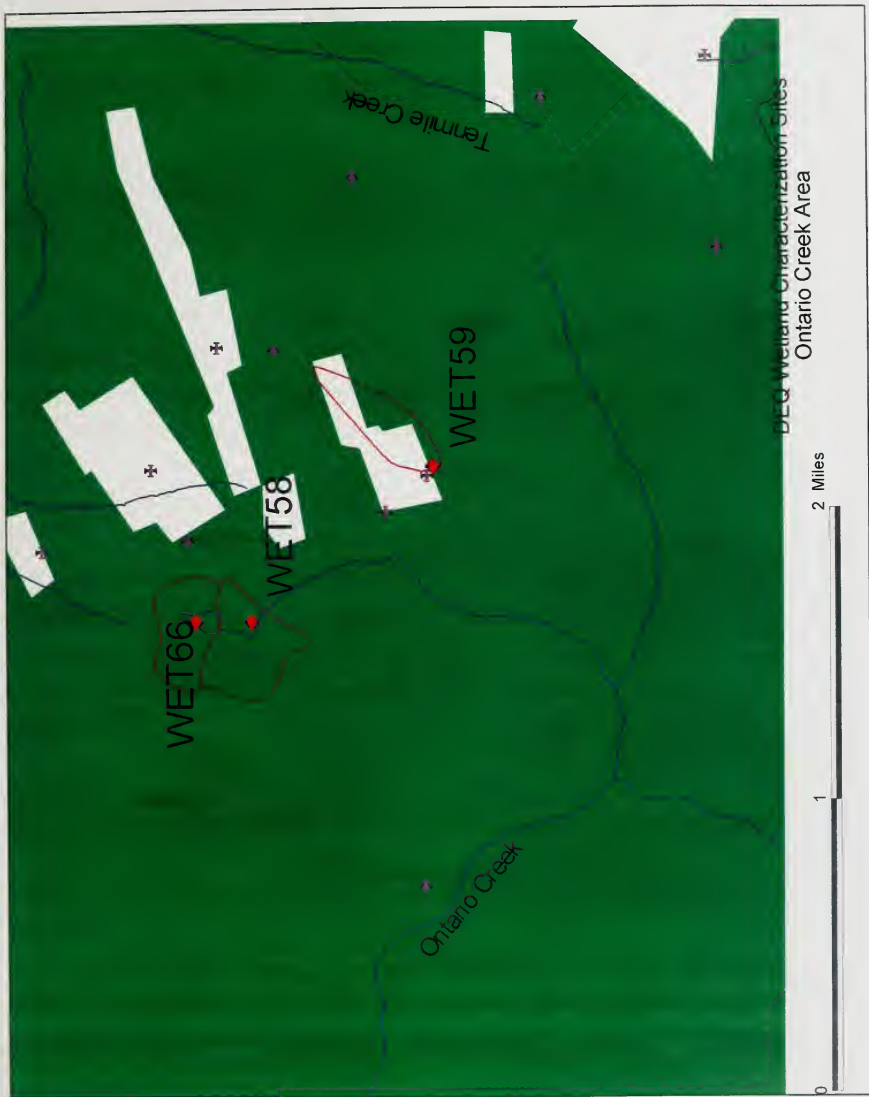
Annual Precipitation in Inches











Wetland: TELEGRAPH CREEK HEADWATERS

Site Code: WET66

7.5 Minute Quad: THREE BROTHERS

Lat: 46 26 25

Long: 112 21 5

Mean Annual Precipitation in Inches: 25.00

Mean Annual Potential Evaporation (Penman) in Inches: 28.00

'Net Precipitation' in Inches: -3.00

Site does not have a mapped surface inlet.

Site has a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 4 acres

Area of contributing drainage basin: 43 acres

Mapped elevation of wetland surface: 7020 ft

Maximum elevation within drainage basin: 7125 ft

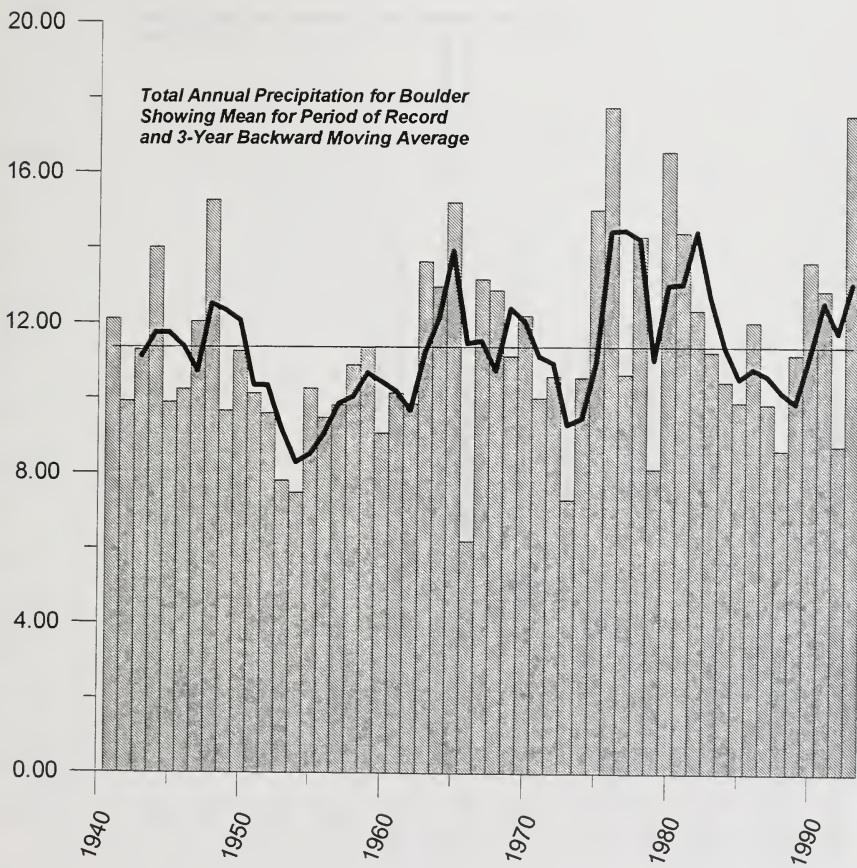
Net relief of contributing basin: 105 ft

COE Hydrogeomorphic class: EXTENS PEAT

Primary surficial geologic unit 112DRFT

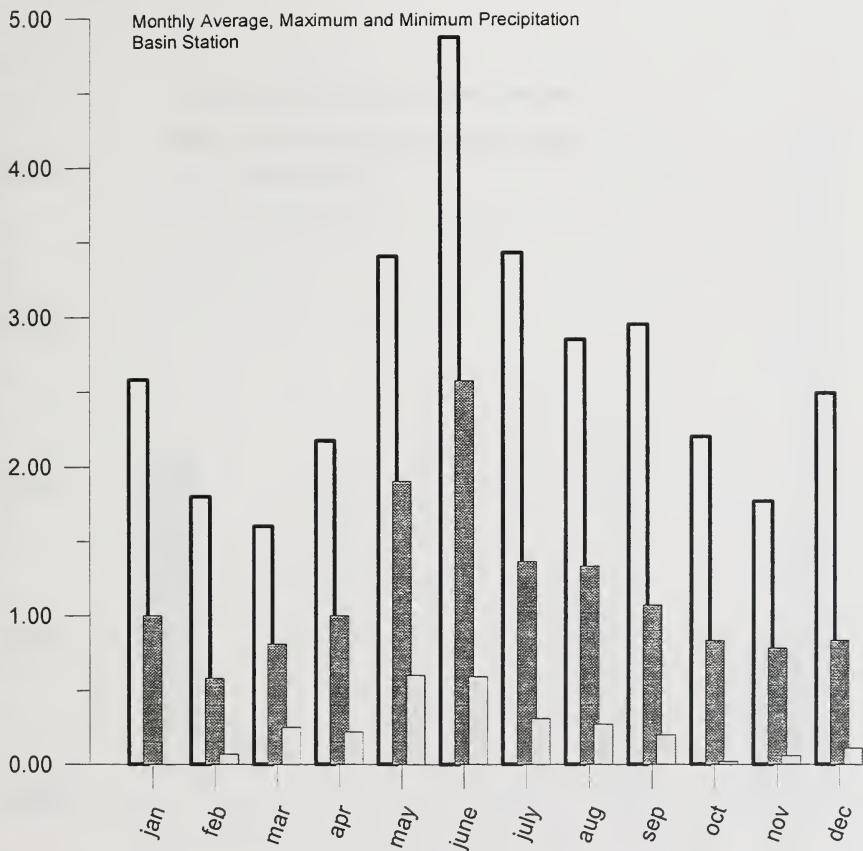
Primary bedrock geologic unit 211ELKM

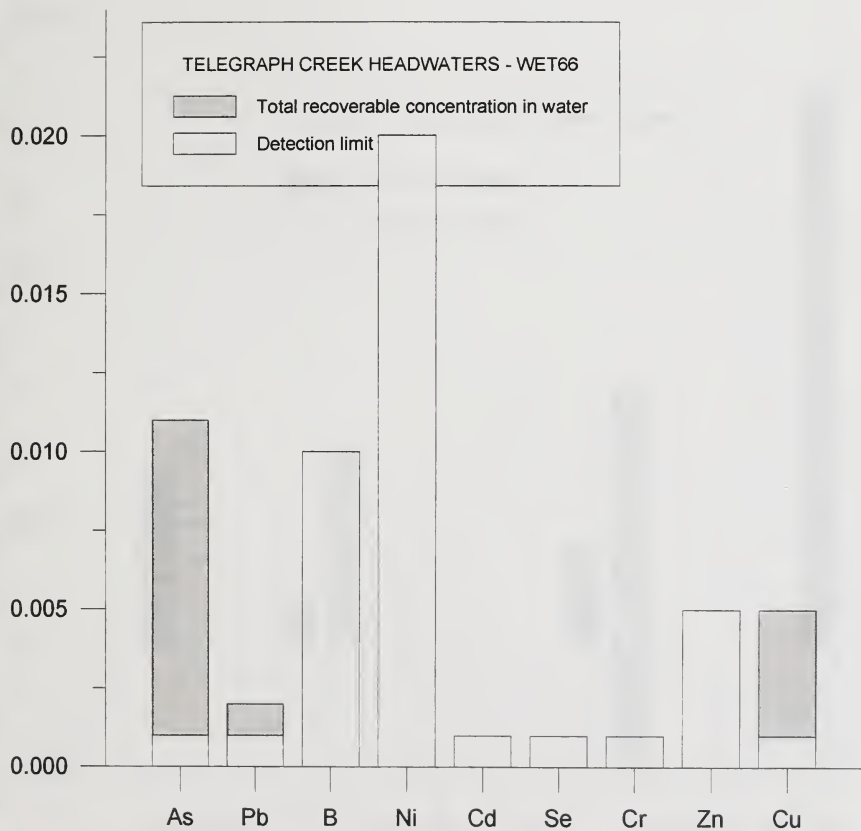
Annual Precipitation in Inches

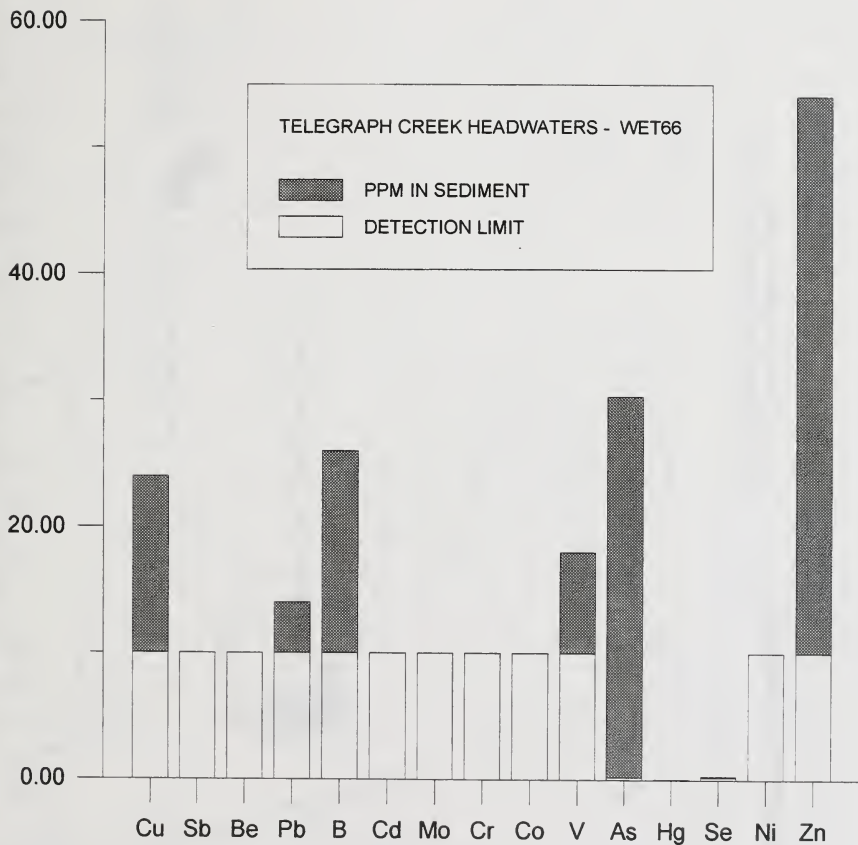


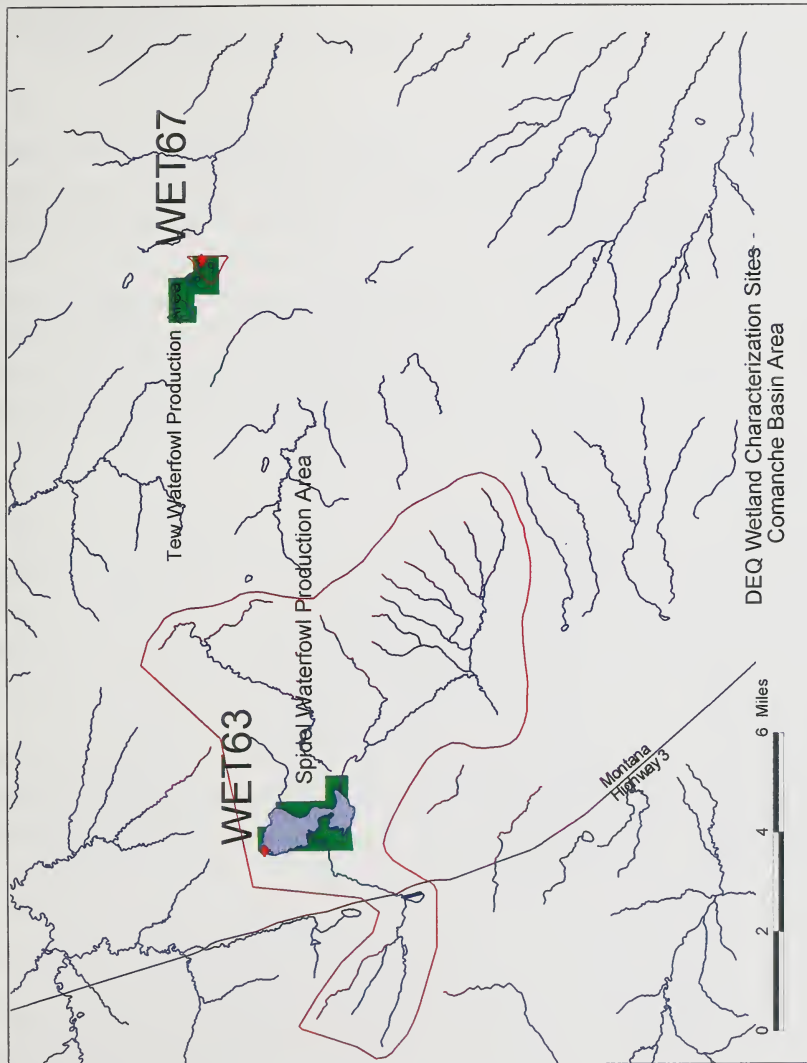
Inches Precipitation

Monthly Average, Maximum and Minimum Precipitation
Basin Station









Wetland: TEW WPA

Site Code: WET67

7.5 Minute Quad: HAY BASIN NORTHEAST

Lat: 46 10 0

Long: 108 36 50

Mean Annual Precipitation in Inches: 15.00

Mean Annual Potential Evaporation (Penman) in Inches: 42.00

'Net Precipitation' in Inches: -27.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 11 acres

Area of contributing drainage basin: 160 acres

Mapped elevation of wetland surface: 3930 ft

Maximum elevation within drainage basin: 4020 ft

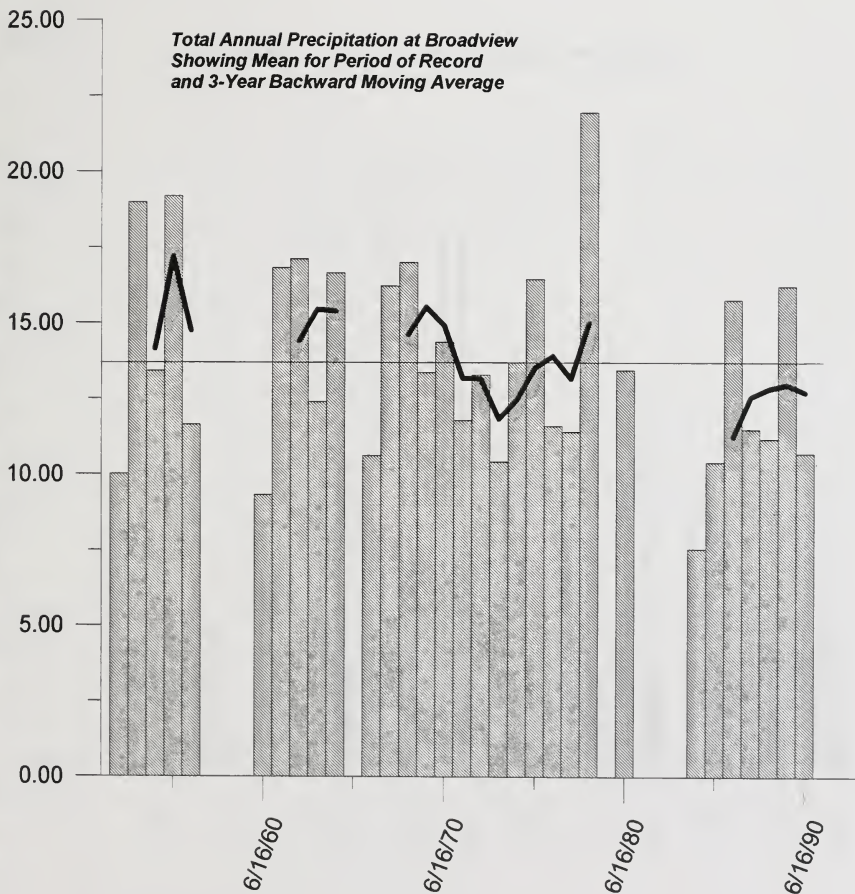
Net relief of contributing basin: 90 ft

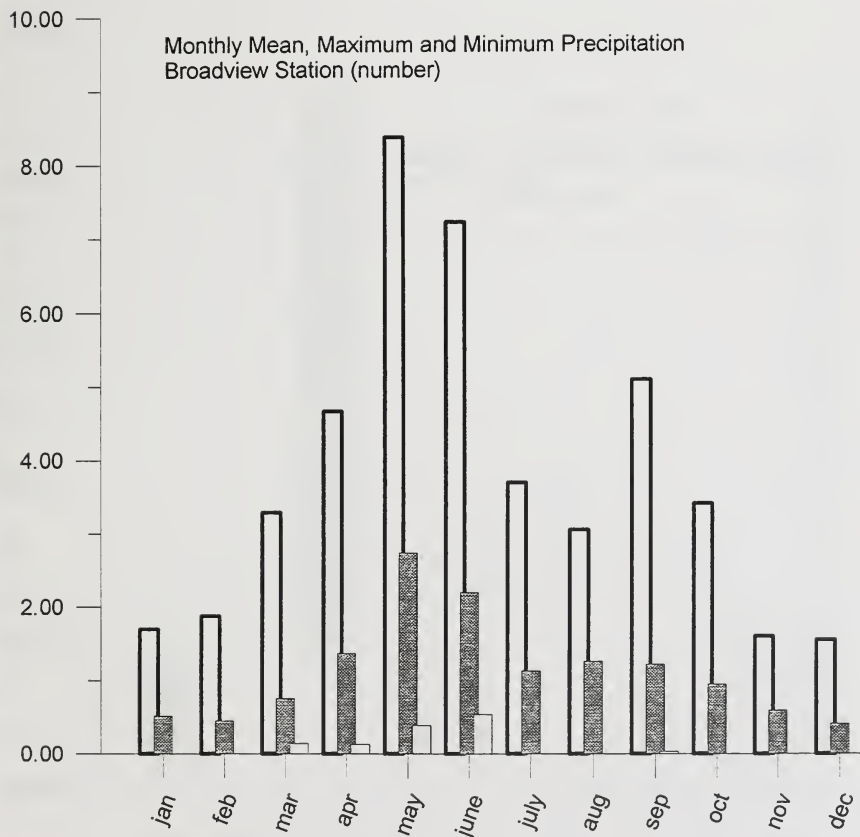
COE Hydrogeomorphic class: DEPRESSIONAL

Primary surficial geologic unit

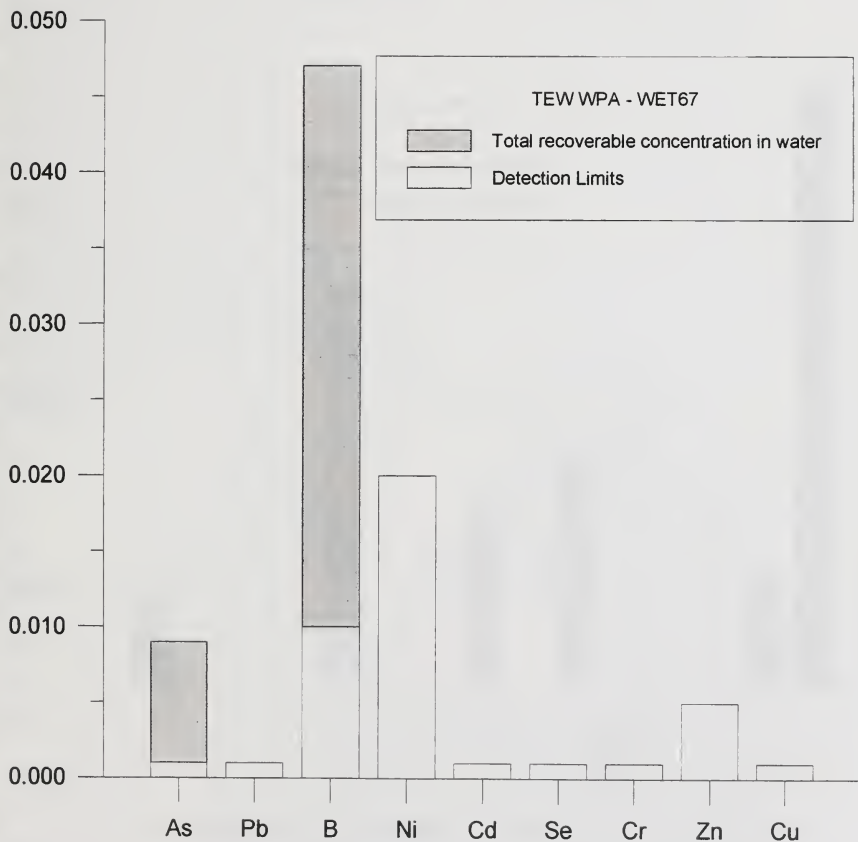
Primary bedrock geologic unit 125LEBO

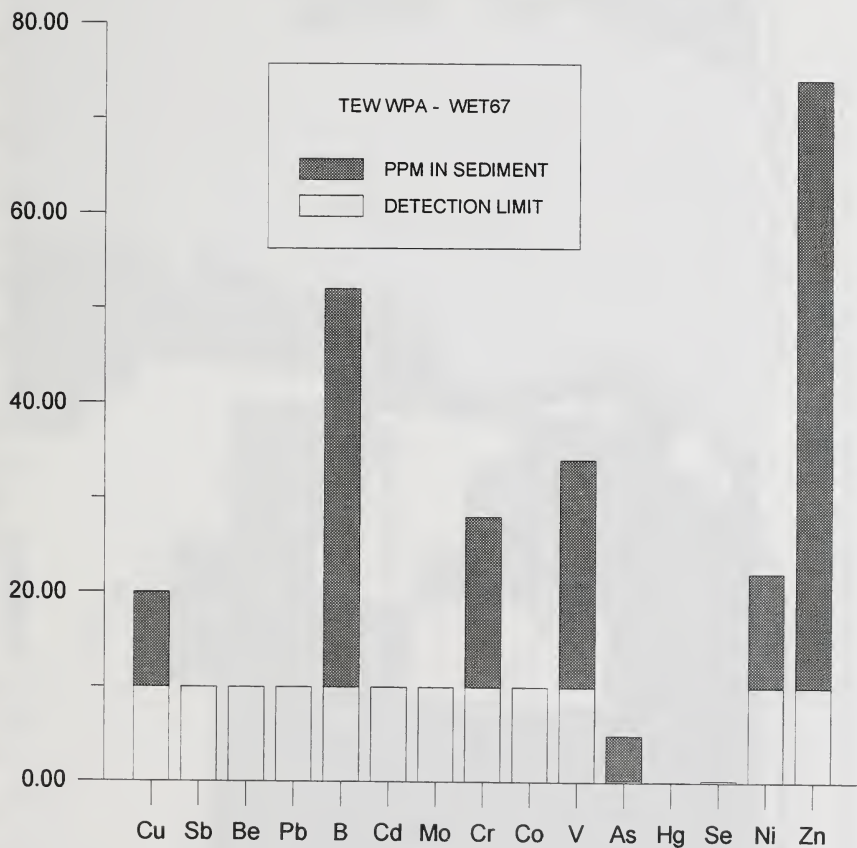
Annual Precipitation in Inches

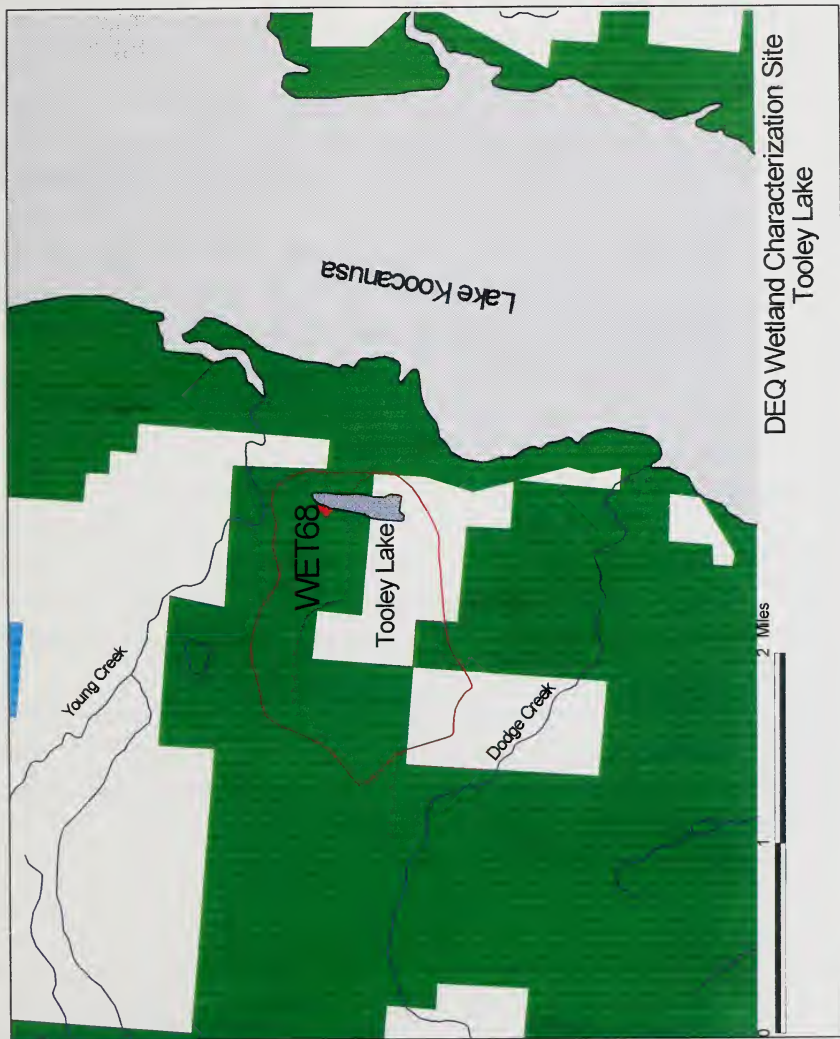




Concentrations in Milligrams per liter







DEQ Wetland Characterization Site
Tooley Lake

Wetland: TOOLEY LAKE
7.5 Minute Quad: REXFORD

Site Code: WET68

Lat: 48 57 20
Long: 115 12 5

Mean Annual Precipitation in Inches:	15.00
Mean Annual Potential Evaporation (Penman) in Inches:	29.00
'Net Precipitation' in Inches:	-14.00

Site has a mapped surface inlet.

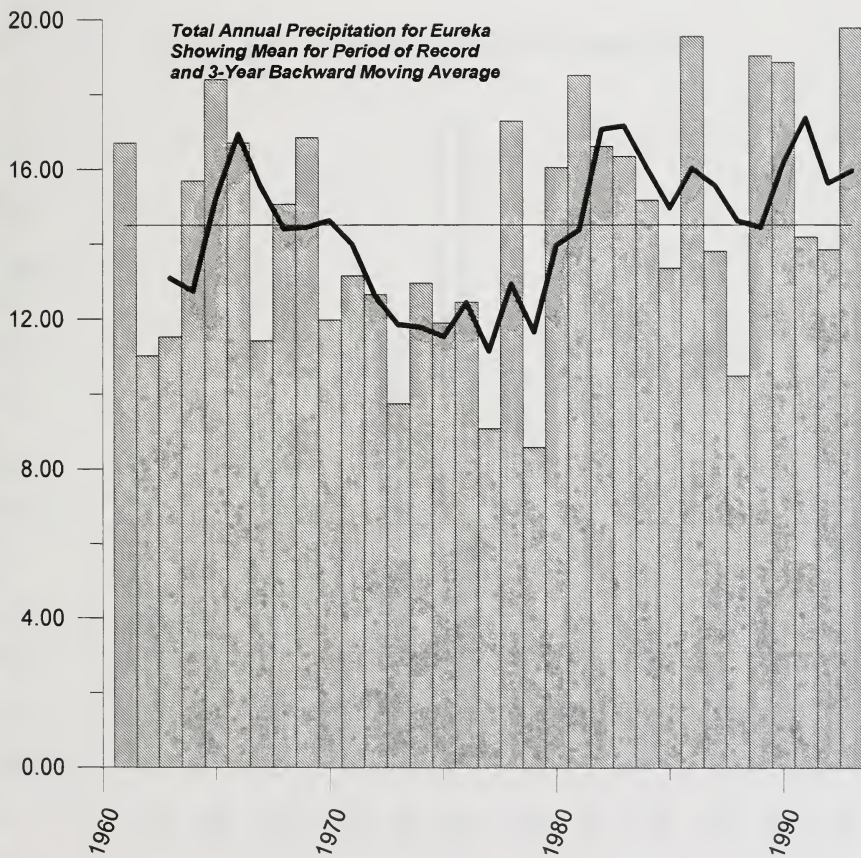
Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

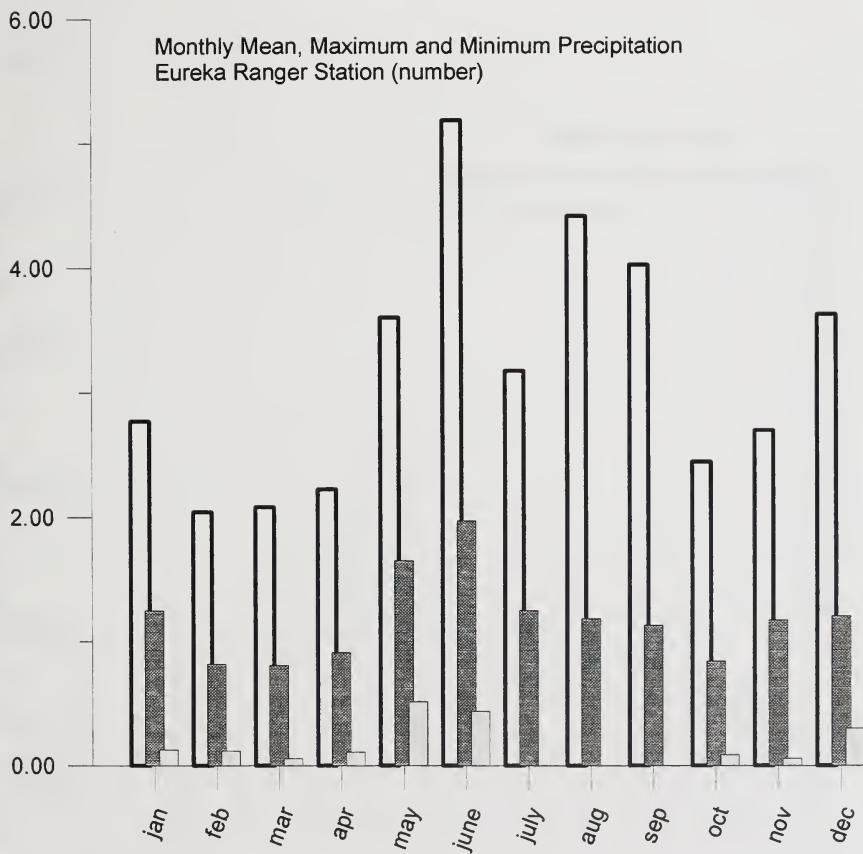
Site does not have known significant water imports.

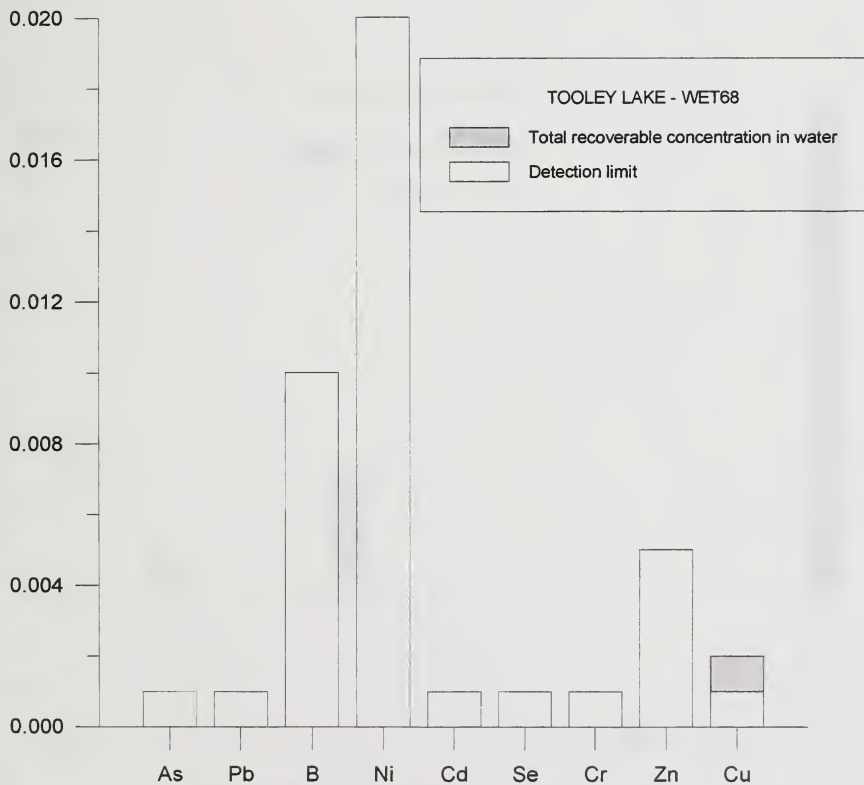
Mapped area of wetland:	29 acres
Area of contributing drainage basin:	860 acres
Mapped elevation of wetland surface:	2537 ft
Maximum elevation within drainage basin:	3205 ft
Net relief of contributing basin:	668 ft

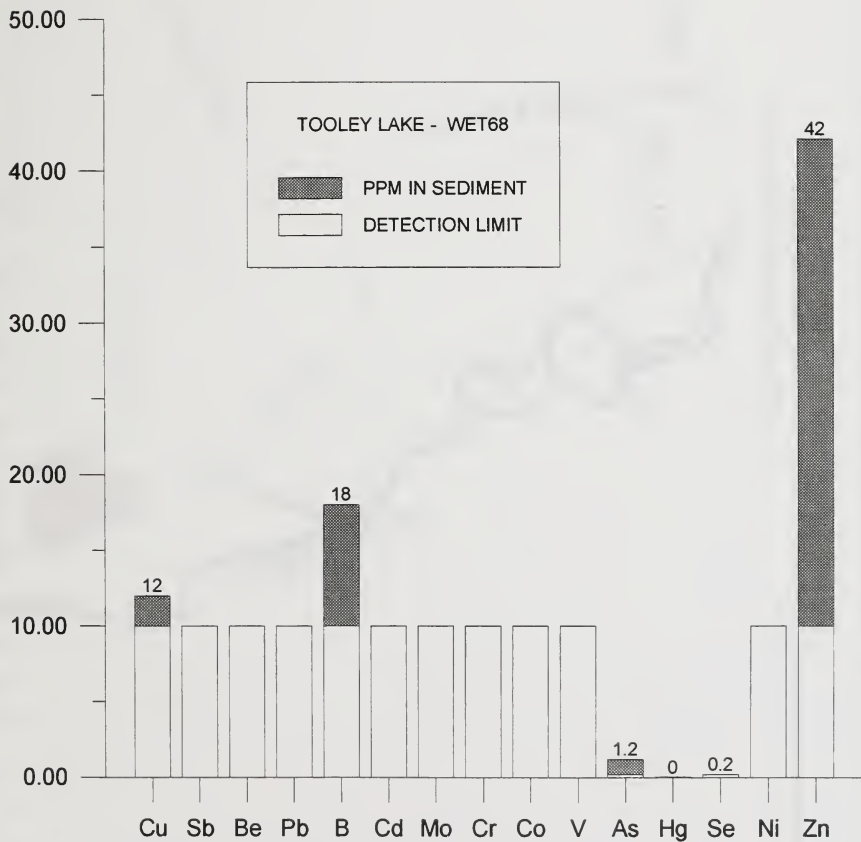
COE Hydrogeomorphic class:	FRINGE
Primary surficial geologic unit	112GLCC
Primary bedrock geologic unit	400RVLL



Monthly Mean, Maximum and Minimum Precipitation
Eureka Ranger Station (number)









Wetland: TOWNSEND VALLEY WETLAND

Site Code: WET69

7.5 Minute Quad: Holker

Lat: 46 15 10

Long: 111 28 35

Mean Annual Precipitation in Inches: 13.00

Mean Annual Potential Evaporation (Penman) in Inches: 41.00

'Net Precipitation' in Inches: -28.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 1 acres

Area of contributing drainage basin: 4 acres

Mapped elevation of wetland surface: 3855 ft

Maximum elevation within drainage basin: 3860 ft

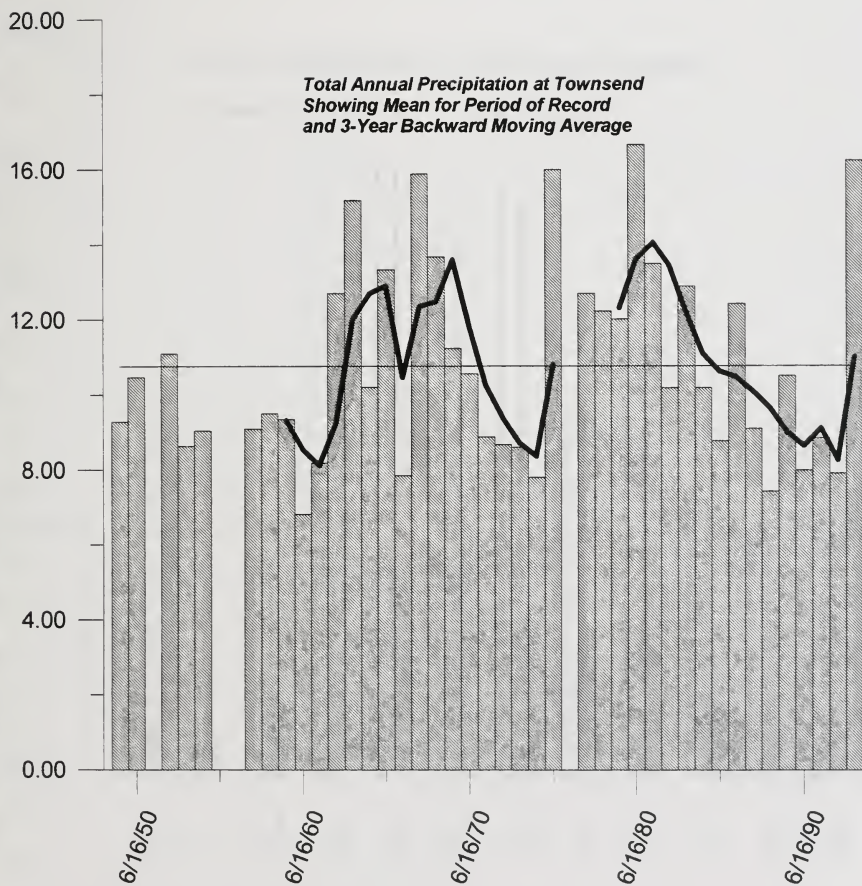
Net relief of contributing basin: 5 ft

COE Hydrogeomorphic class: DEPRESSIONAL

Primary surficial geologic unit 110ALVM

Primary bedrock geologic unit 120SDMS

Annual Precipitation in Inches



6.00

Monthly Average, Maximum and Minimum Precipitation

Townsend

4.00

2.00

0.00

jan

feb

mar

apr

may

june

july

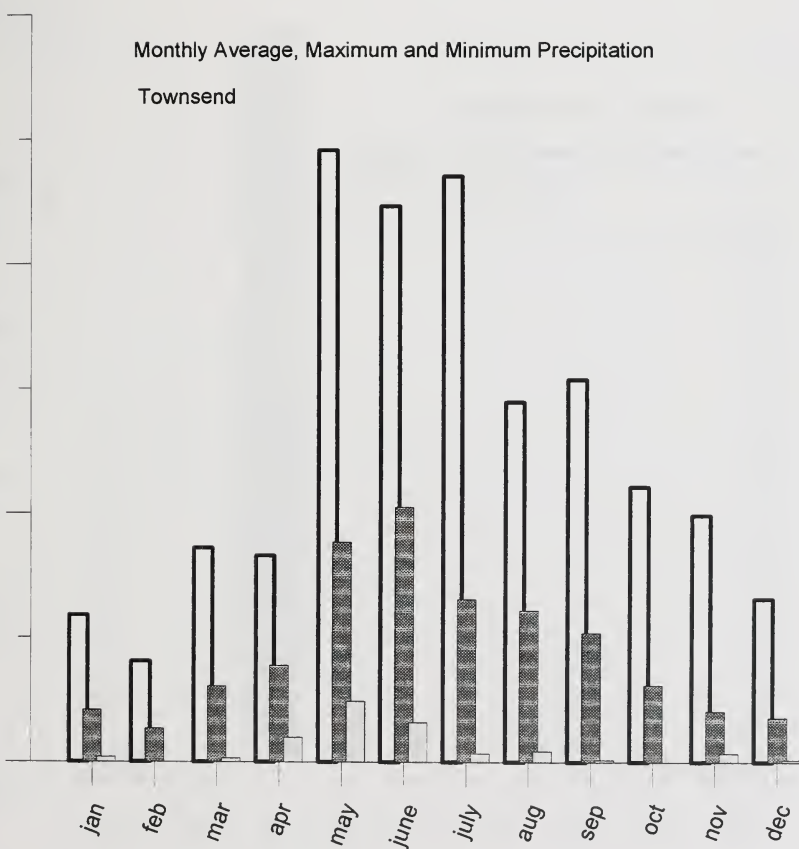
aug

sep

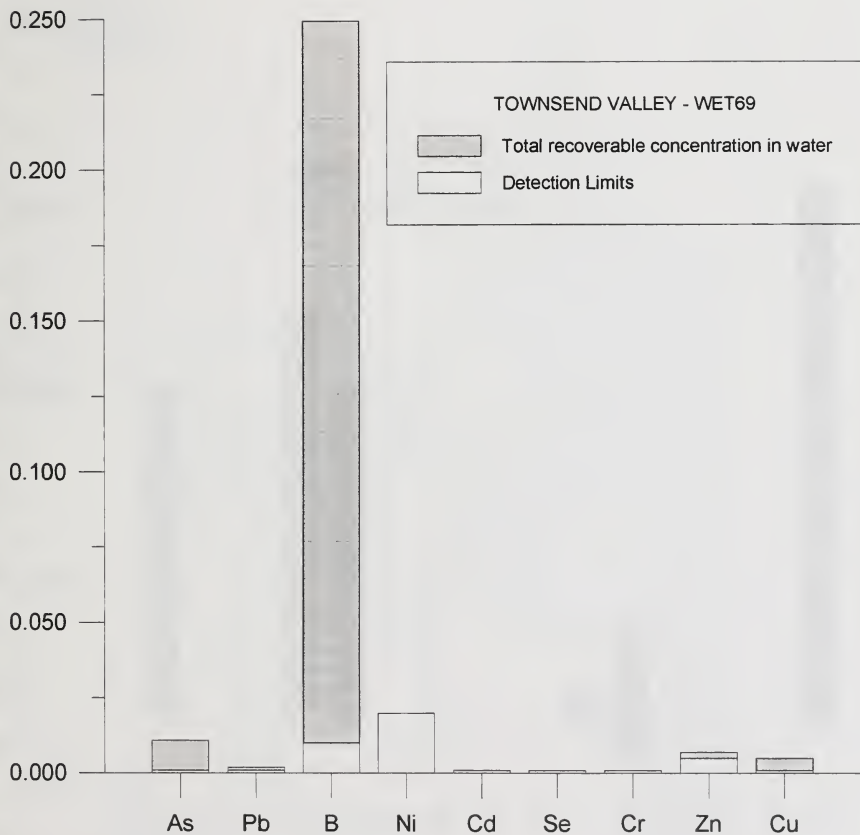
oct

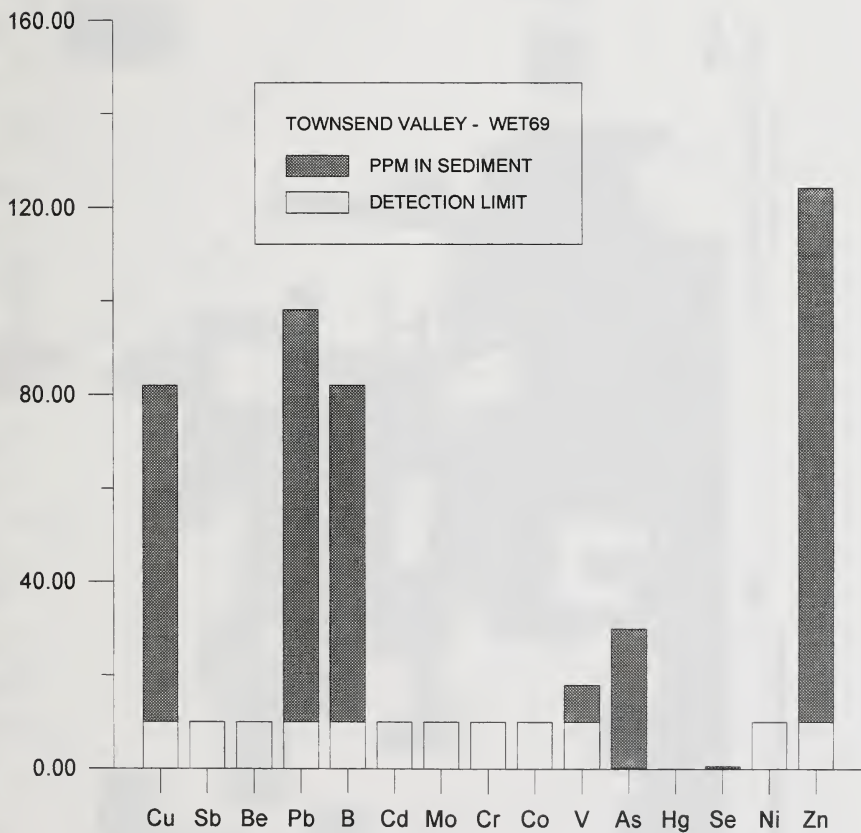
nov

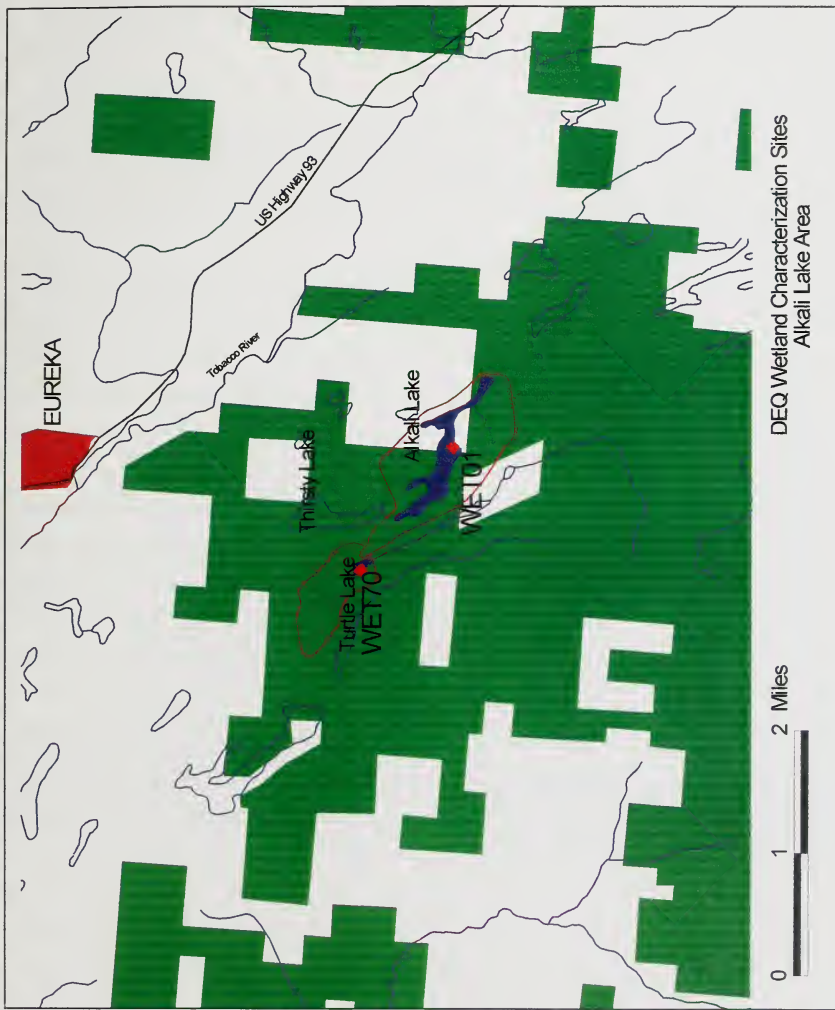
dec



Concentrations in Milligrams per liter







Wetland: TURTLE LAKE

Site Code: WET70

7.5 Minute Quad: EUREKA SOUTH

Lat: 48 50 35

Long: 115 3 50

Mean Annual Precipitation in Inches: 19.00

Mean Annual Potential Evaporation (Penman) in Inches: 30.00

'Net Precipitation' in Inches: -11.00

Site has a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 7 acres

Area of contributing drainage basin: 200 acres

Mapped elevation of wetland surface: 3030 ft

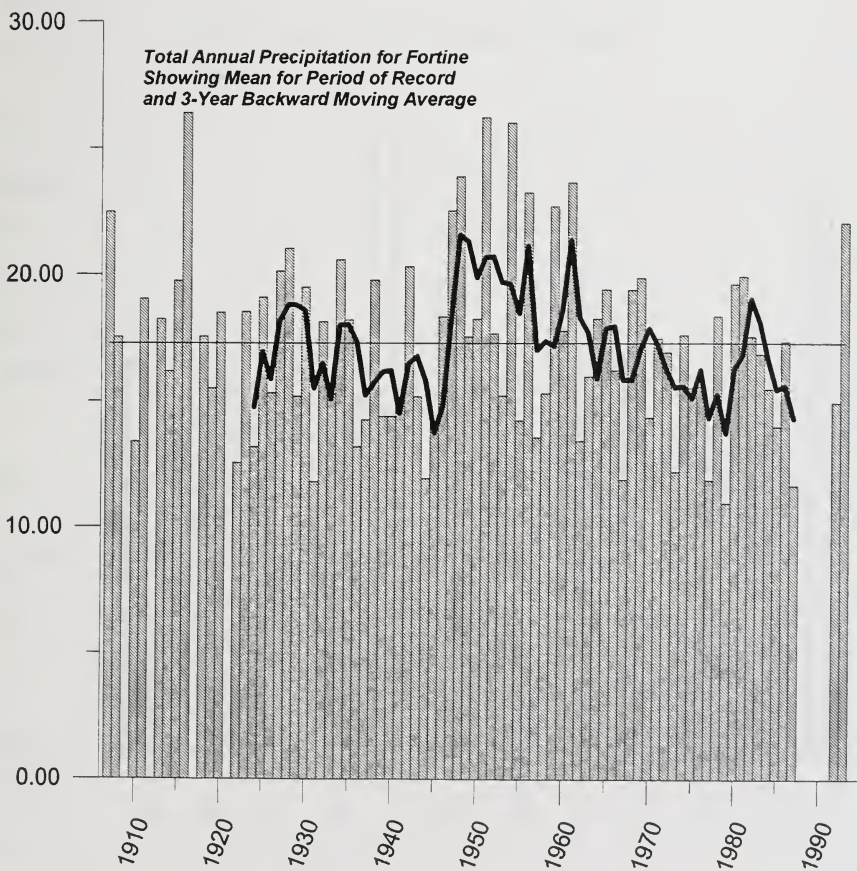
Maximum elevation within drainage basin: 3265 ft

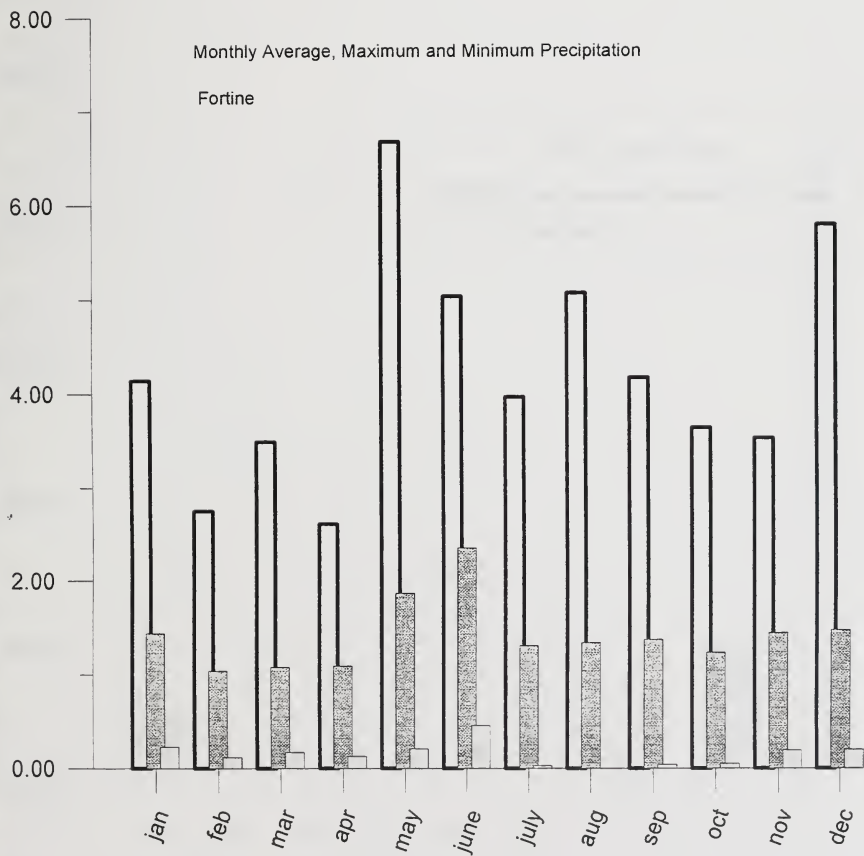
Net relief of contributing basin: 235 ft

COE Hydrogeomorphic class: FRINGE

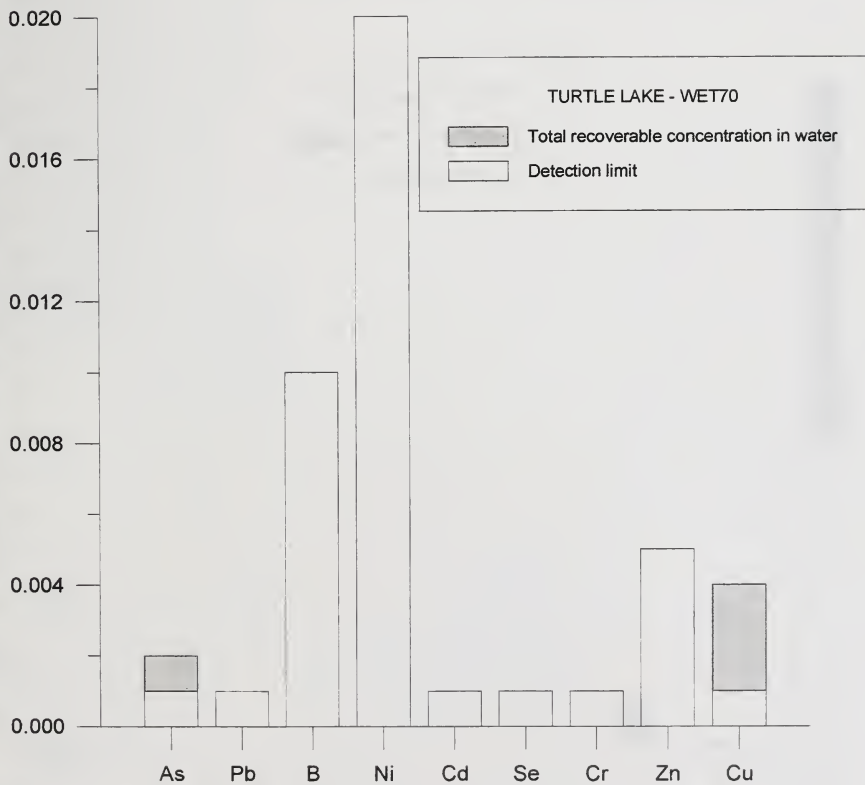
Primary surficial geologic unit 112TILL

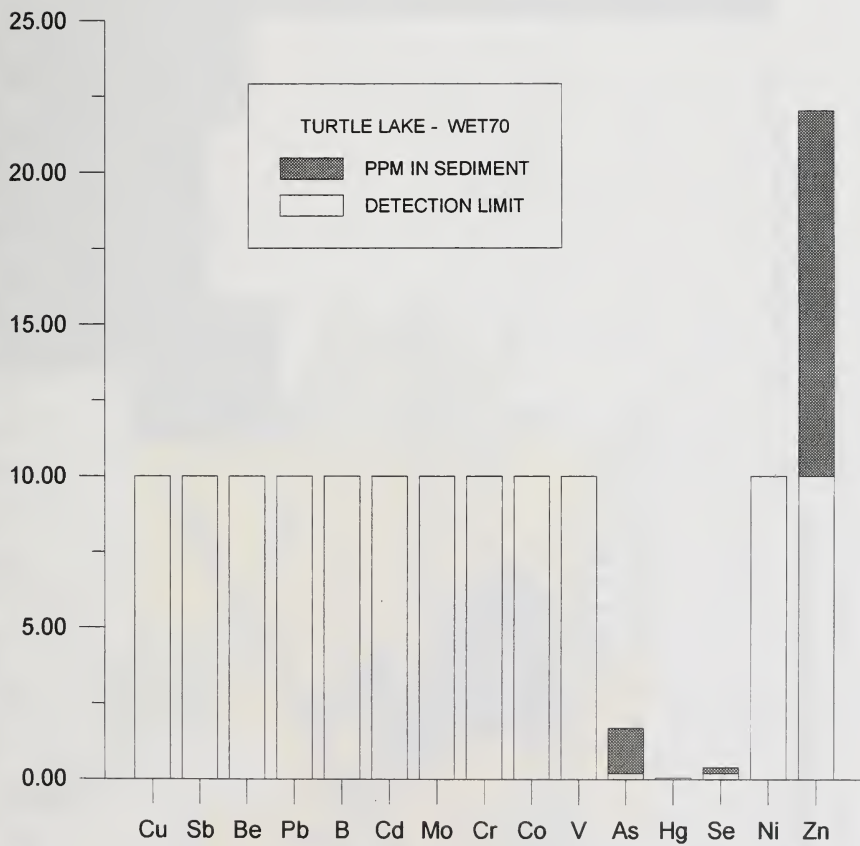
Primary bedrock geologic unit 400BELT

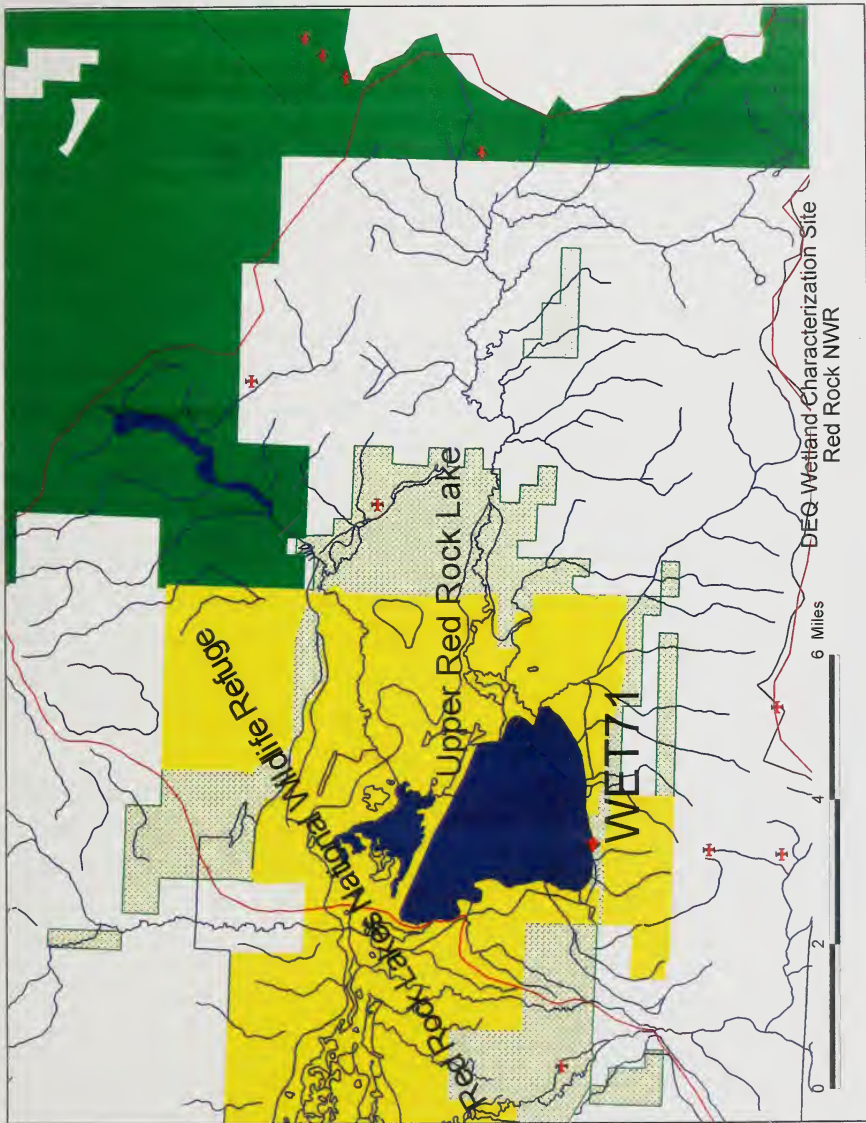




Concentrations in Milligrams per liter







Wetland: UPPER RED ROCK LAKE
7.5 Minute Quad: UPPER RED ROCK

Site Code: WET71

Lat: 44 35 35
Long: 111 43 40

Mean Annual Precipitation in Inches: 25.00
Mean Annual Potential Evaporation (Penman) in Inches: 30.00
'Net Precipitation' in Inches: -5.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 2905 acres
Area of contributing drainage basin: 81750 acres
Mapped elevation of wetland surface: 6610 ft
Maximum elevation within drainage basin: 10203 ft
Net relief of contributing basin: 3593 ft

COE Hydrogeomorphic class: FRINGE
Primary surficial geologic unit 110CNZC
Primary bedrock geologic unit 110CNZC

Annual Precipitation in Inches

30.00

**Total Annual Precipitation for Lakeview
Showing Mean for Period of Record
and 3-Year Backward Moving Average**

20.00

10.00

0.00

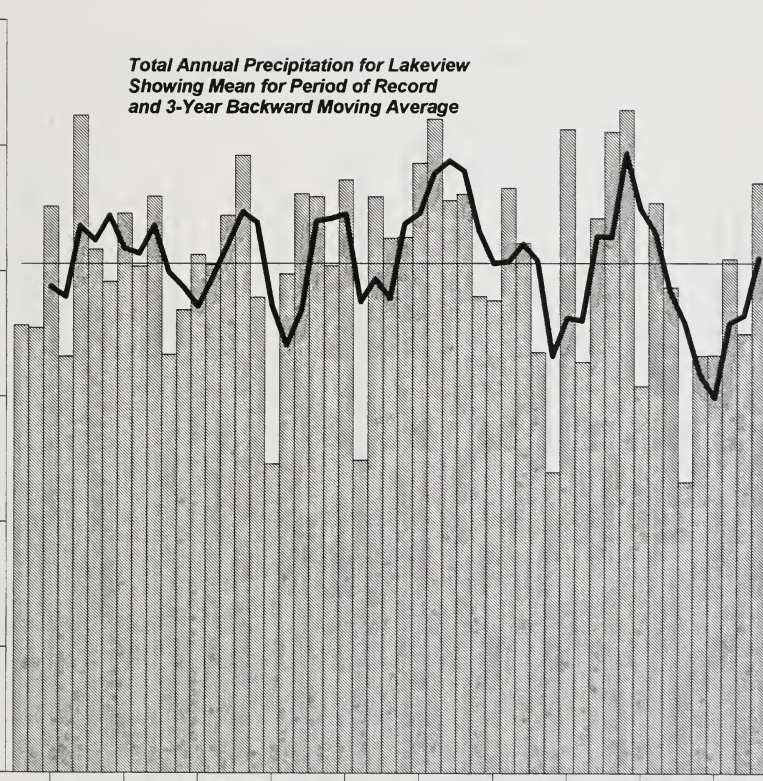
1950

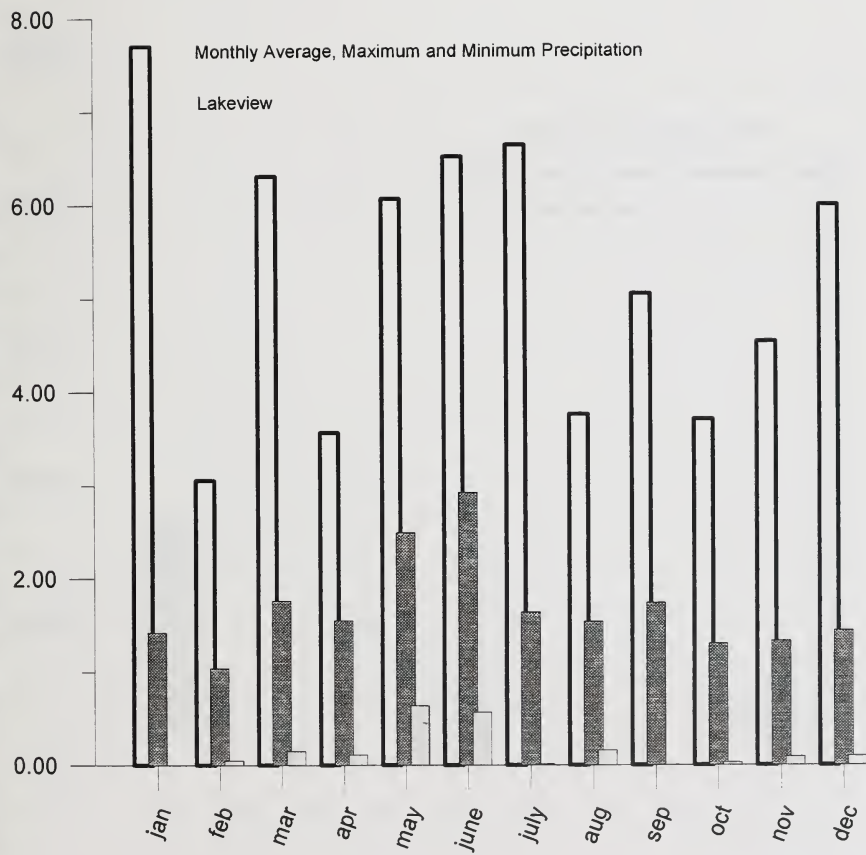
1960

1970

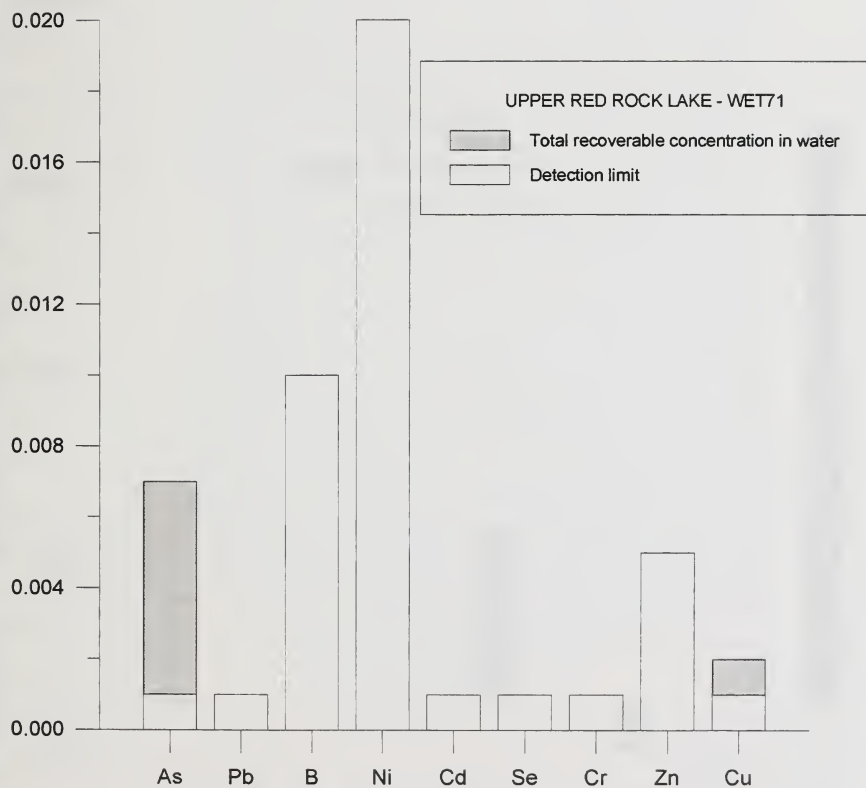
1980

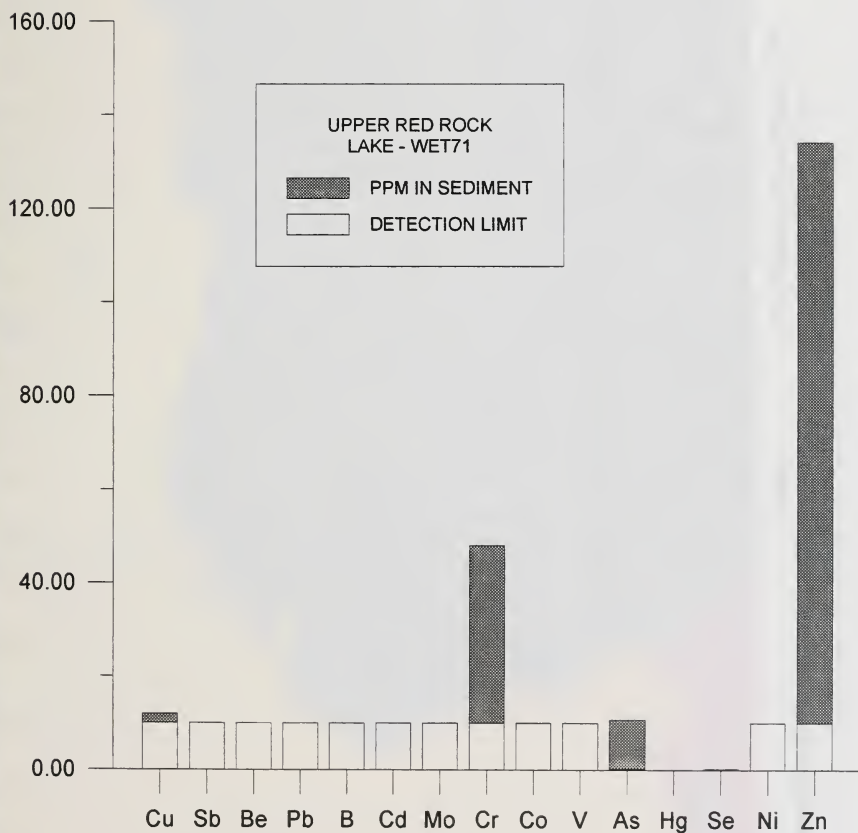
1990





Concentrations in Milligrams per liter







Wetland: UPPER STILLWATER RIVER WETLAND

Site Code: WET72

7.5 Minute Quad: COOKE CITY

Lat: 45 4 43

Long: 109 59 38

Mean Annual Precipitation in Inches: 70.00

Mean Annual Potential Evaporation (Penman) in Inches: 26.00

'Net Precipitation' in Inches: 44.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 300 acres

Area of contributing drainage basin: 3630 acres

Mapped elevation of wetland surface: 8470 ft

Maximum elevation within drainage basin: 10500 ft

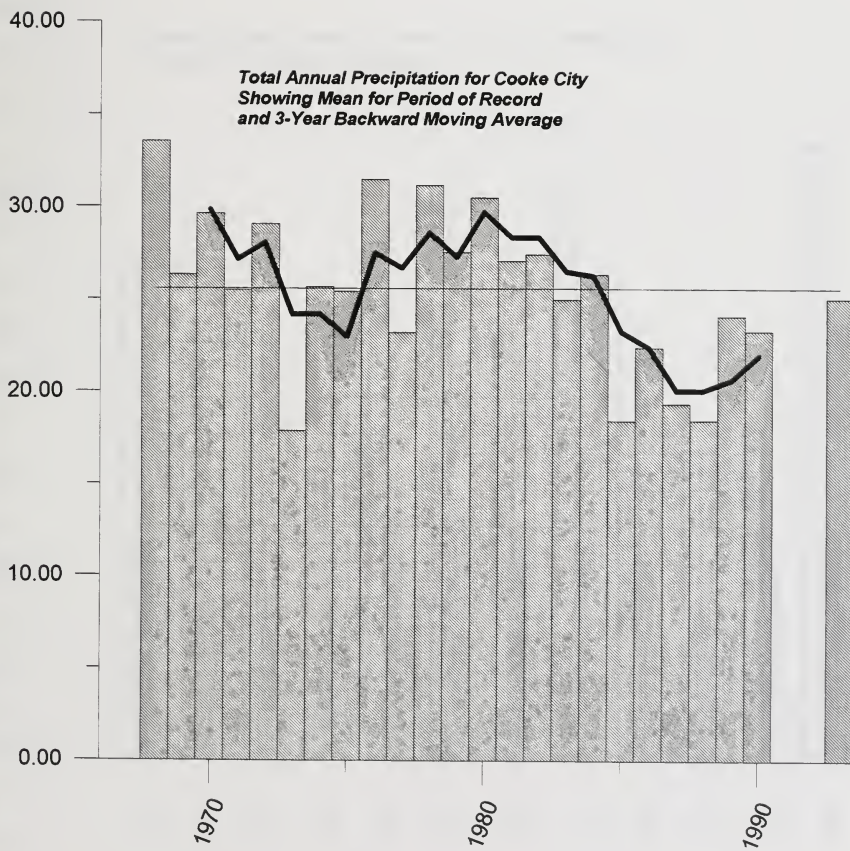
Net relief of contributing basin: 2030 ft

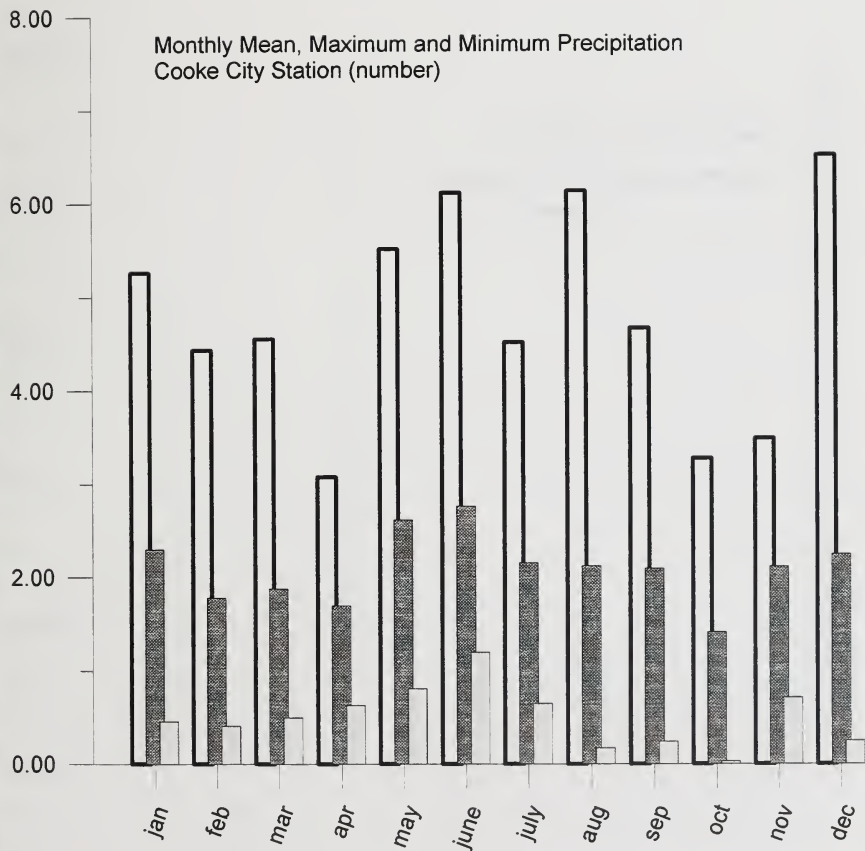
COE Hydrogeomorphic class: RIVERINE

Primary surficial geologic unit 111ALVM

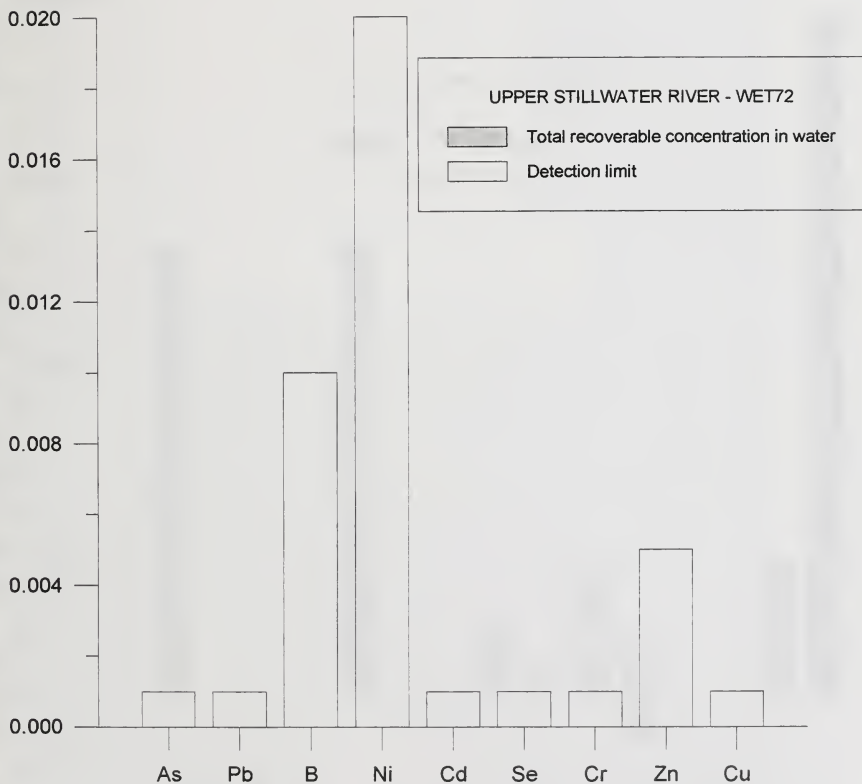
Primary bedrock geologic unit 120VLCC

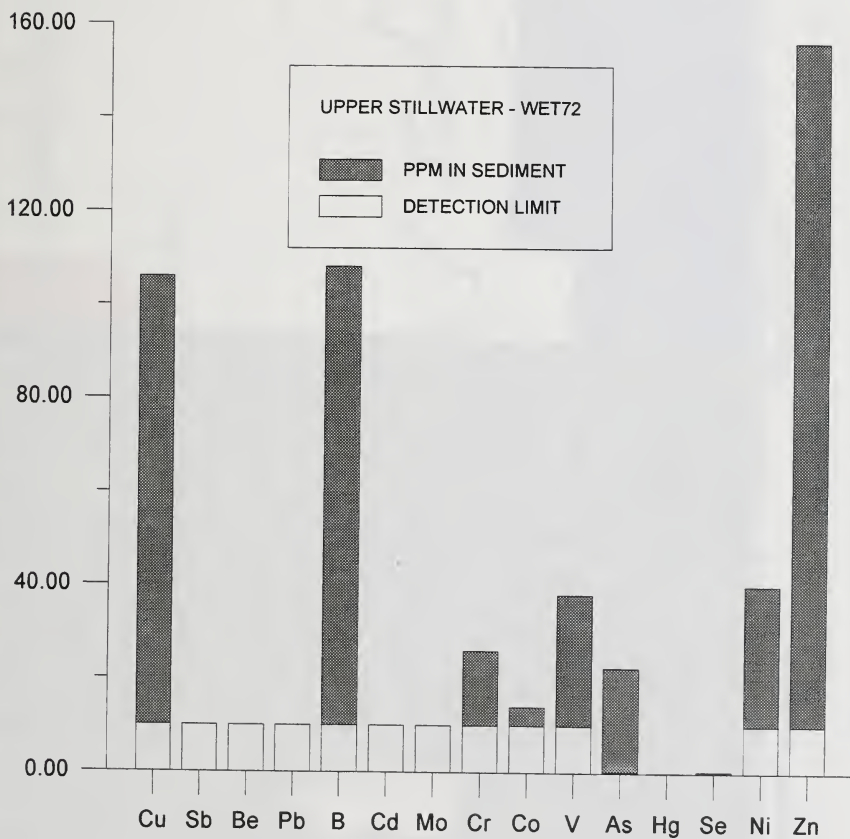
Annual Precipitation in Inches

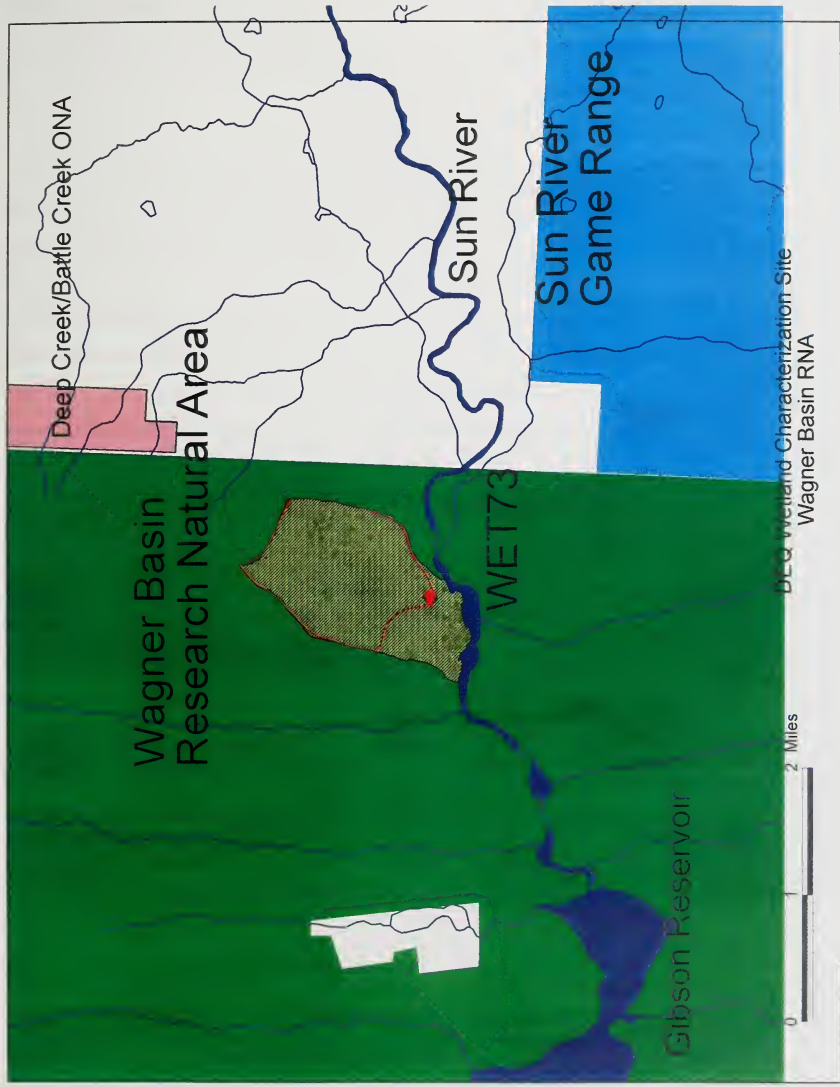




Concentrations in Milligrams per liter







Wetland: WAGNER BASIN RNA

Site Code: WET73

7.5 Minute Quad: SAWTOOTH RIDGE

Lat: 47 37 20

Long: 112 42 45

Mean Annual Precipitation in Inches: 25.00

Mean Annual Potential Evaporation (Penman) in Inches: 31.00

'Net Precipitation' in Inches: -6.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 10 acres

Area of contributing drainage basin: 725 acres

Mapped elevation of wetland surface: 4550 ft

Maximum elevation within drainage basin: 7668 ft

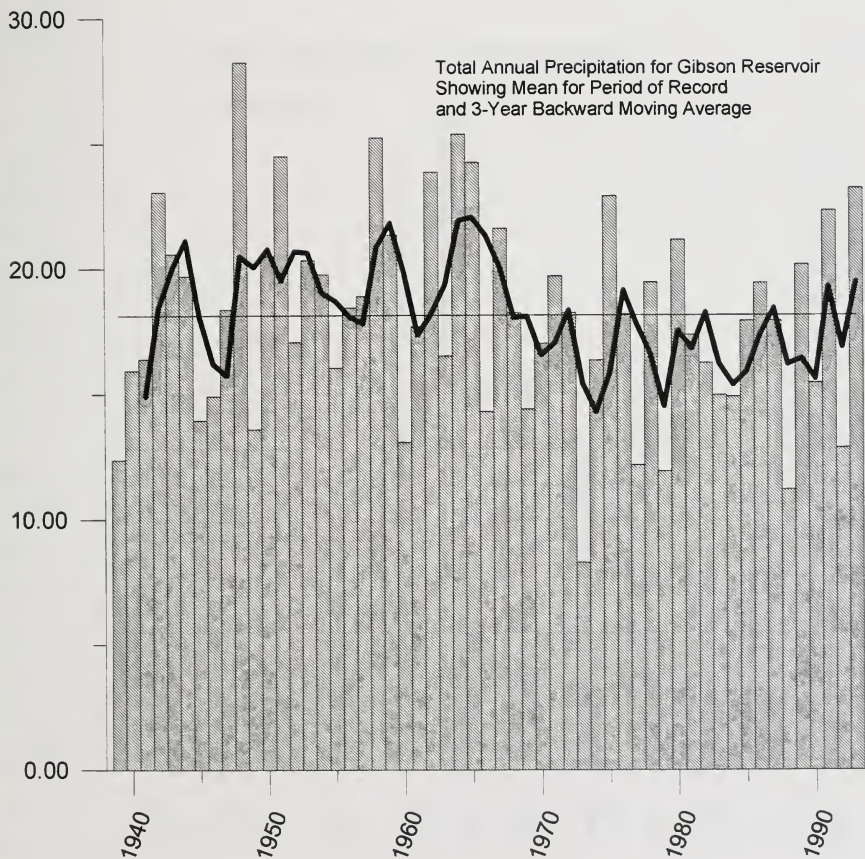
Net relief of contributing basin: 3118 ft

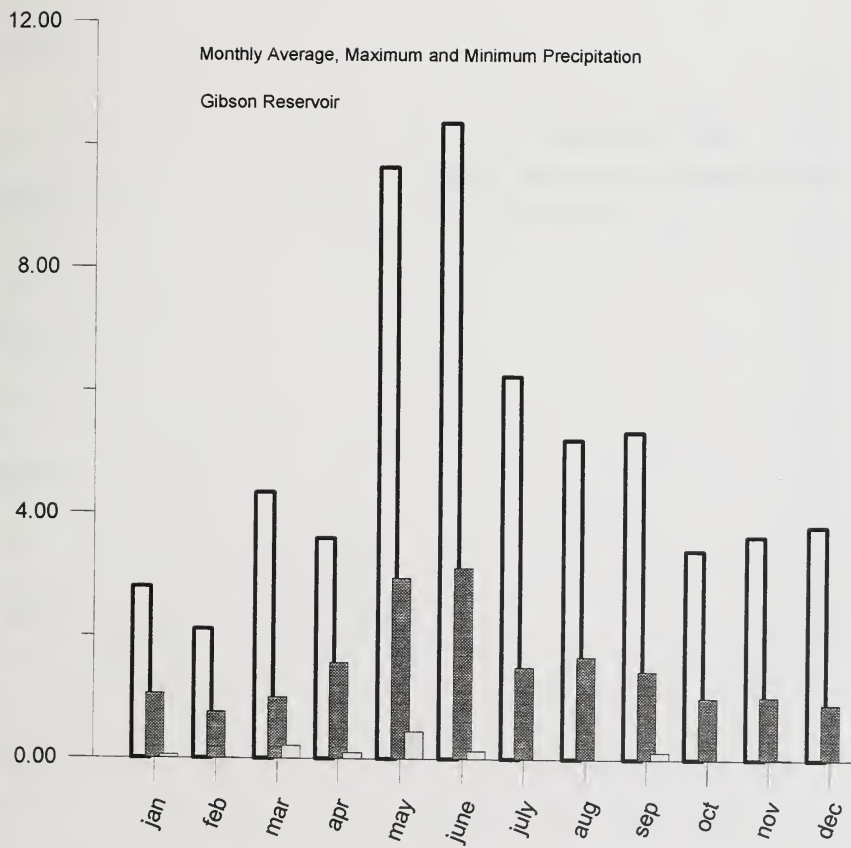
COE Hydrogeomorphic class: RIVERINE

Primary surficial geologic unit

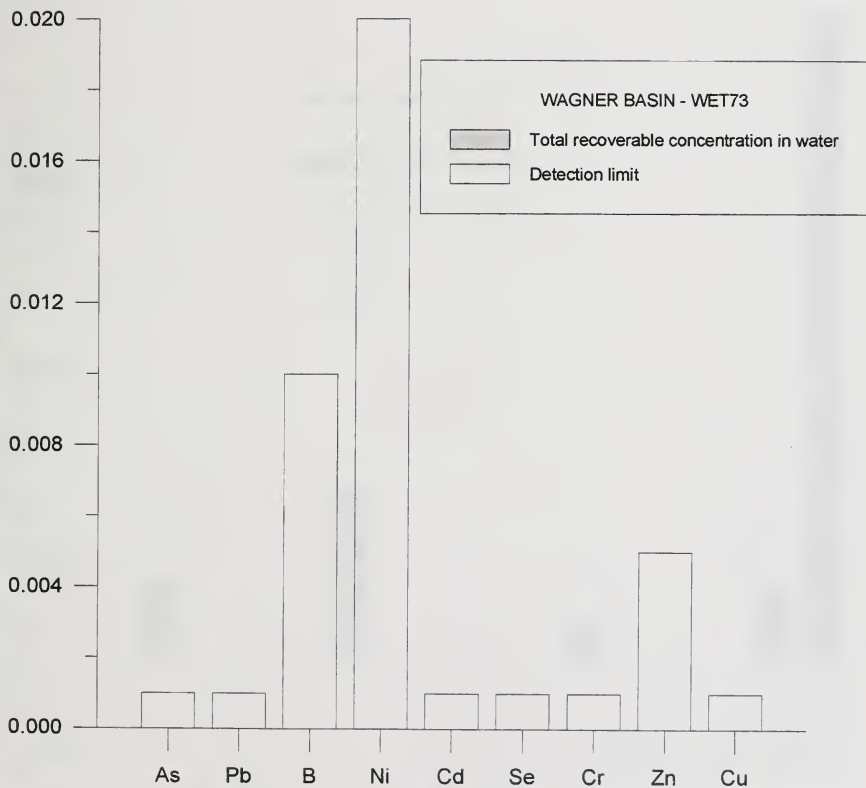
Primary bedrock geologic unit 300PLZC

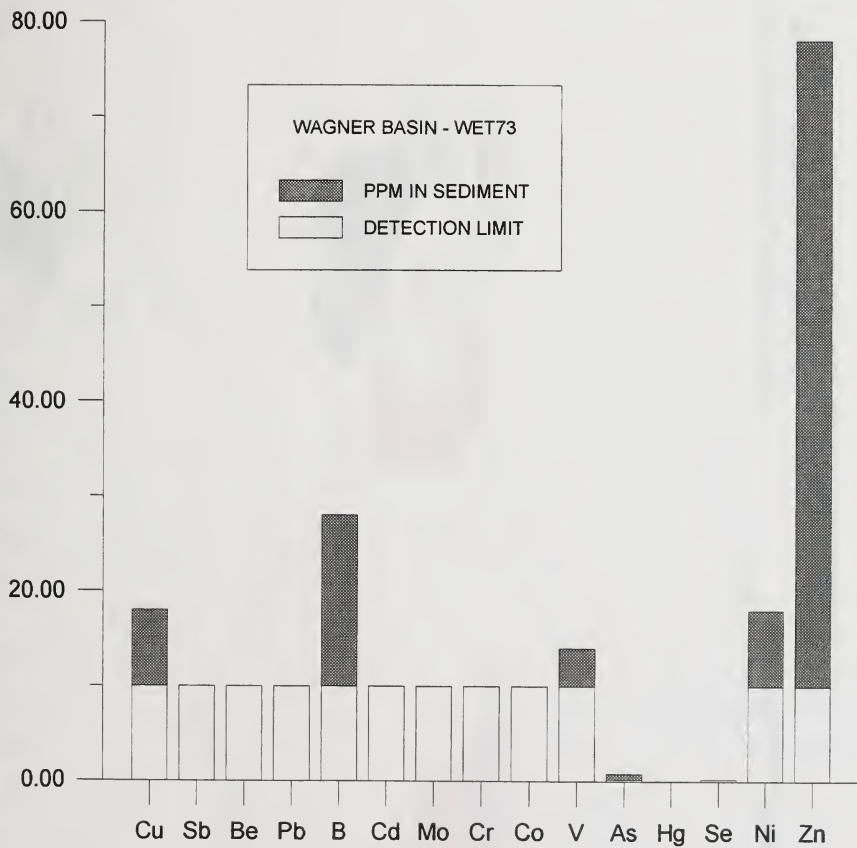
Annual Precipitation in Inches

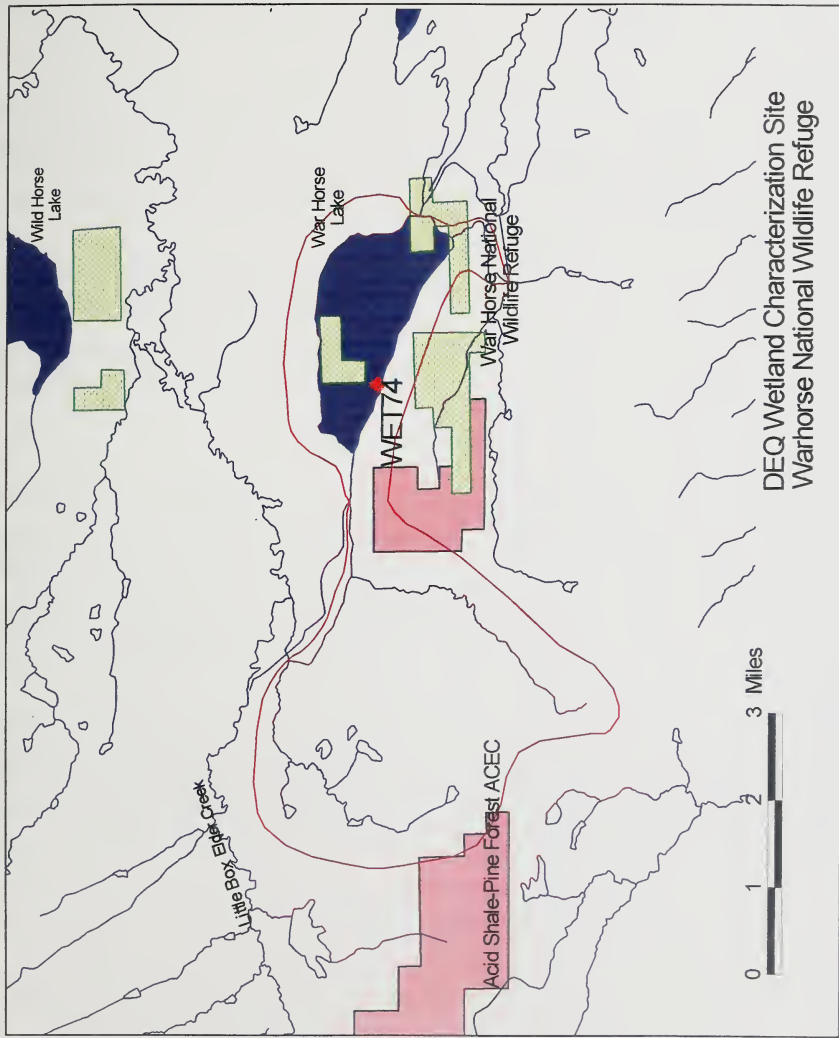




Concentrations in Milligrams per liter







Wetland: WARHORSE NWR

Site Code: WET74

7.5 Minute Quad: TIEGEN

Lat: 47 7 5

Long: 108 34 5

Mean Annual Precipitation in Inches:	13.00
Mean Annual Potential Evaporation (Penman) in Inches:	41.00
'Net Precipitation' in Inches:	-28.00

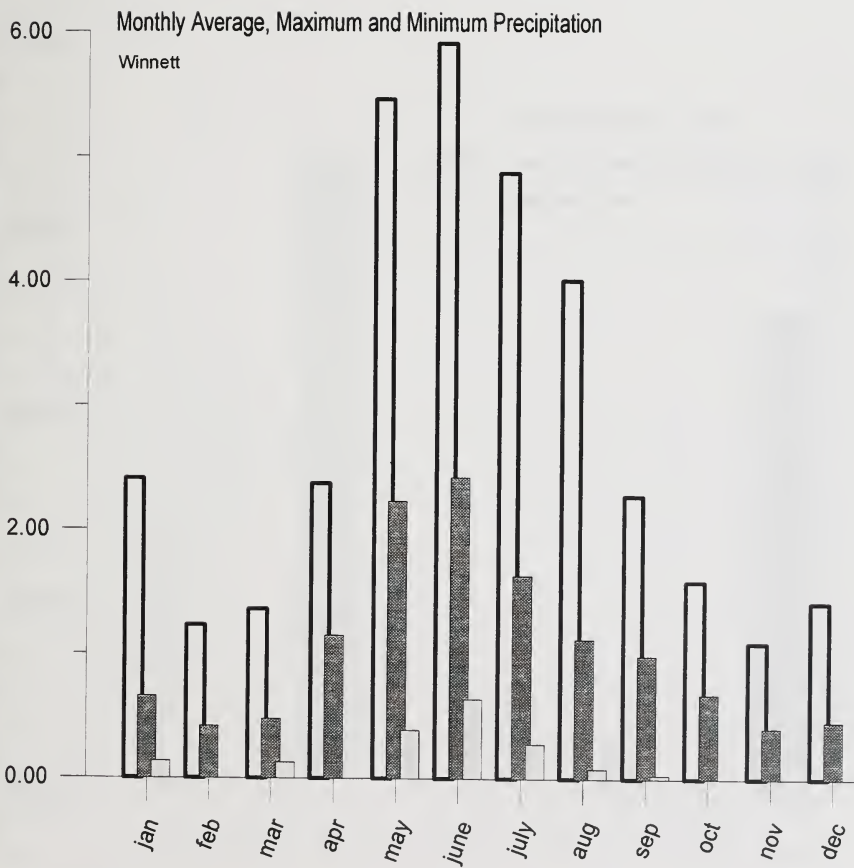
Site has a mapped surface inlet.

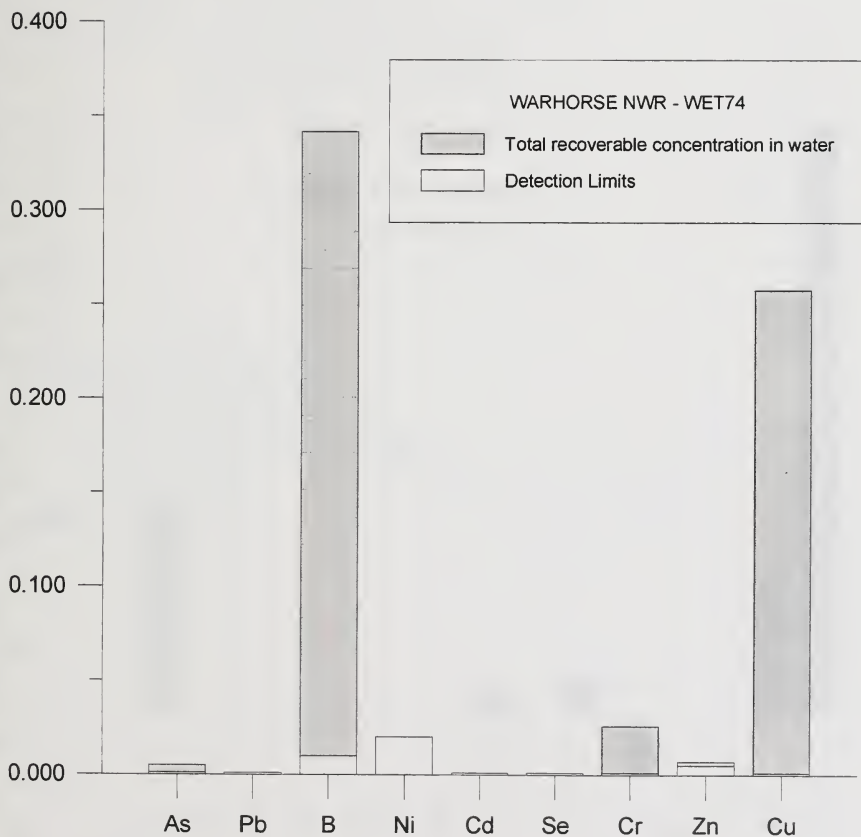
Site has a mapped surface outlet.

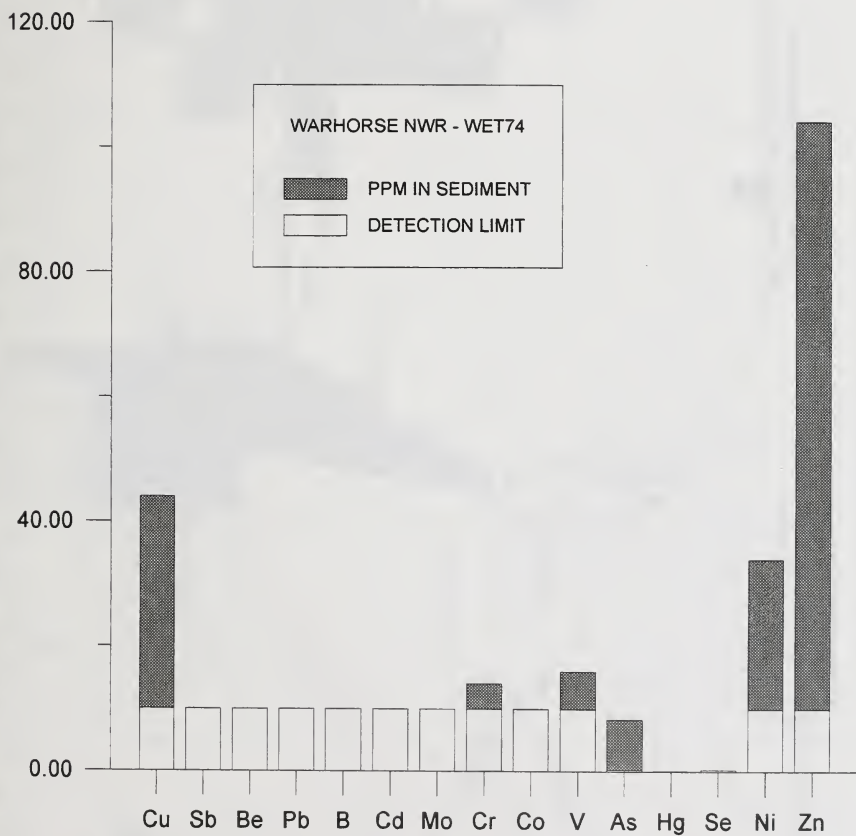
Site is artificially impounded.

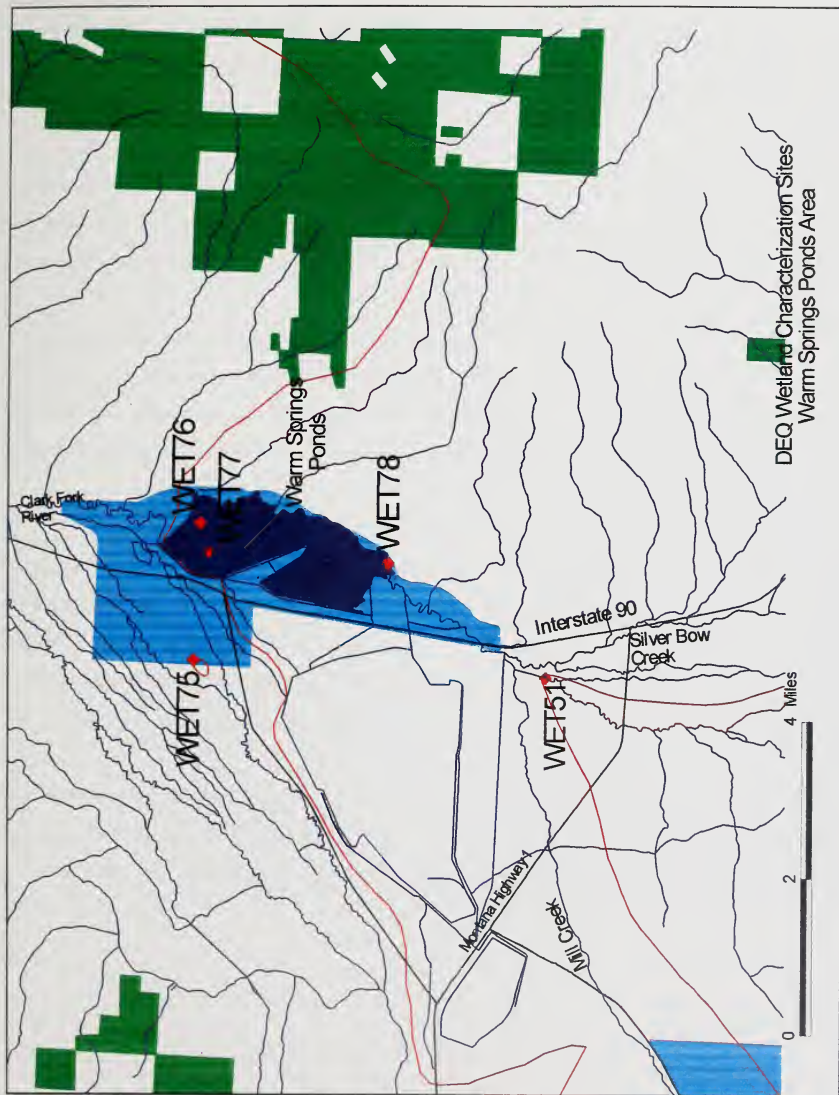
Site has significant water imports.

Mapped area of wetland:	1445 acres
Area of contributing drainage basin:	9890 acres
Mapped elevation of wetland surface:	3135 ft
Maximum elevation within drainage basin:	3591 ft
Net relief of contributing basin:	456 ft
COE Hydrogeomorphic class:	DEPRESSIONAL
Primary surficial geologic unit	110"LAC"
Primary bedrock geologic unit	211CLRD









Wetland: WARM SPRINGS DUCKS UNLIMITED POND

Site Code: WET75

7.5 Minute Quad: WARM SPRINGS

Lat: 46 10 30

Long: 112 48 20

Mean Annual Precipitation in Inches: 13.00

Mean Annual Potential Evaporation (Penman) in Inches: 33.00

'Net Precipitation' in Inches: -20.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 1 acres

Area of contributing drainage basin: 21 acres

Mapped elevation of wetland surface: 4855 ft

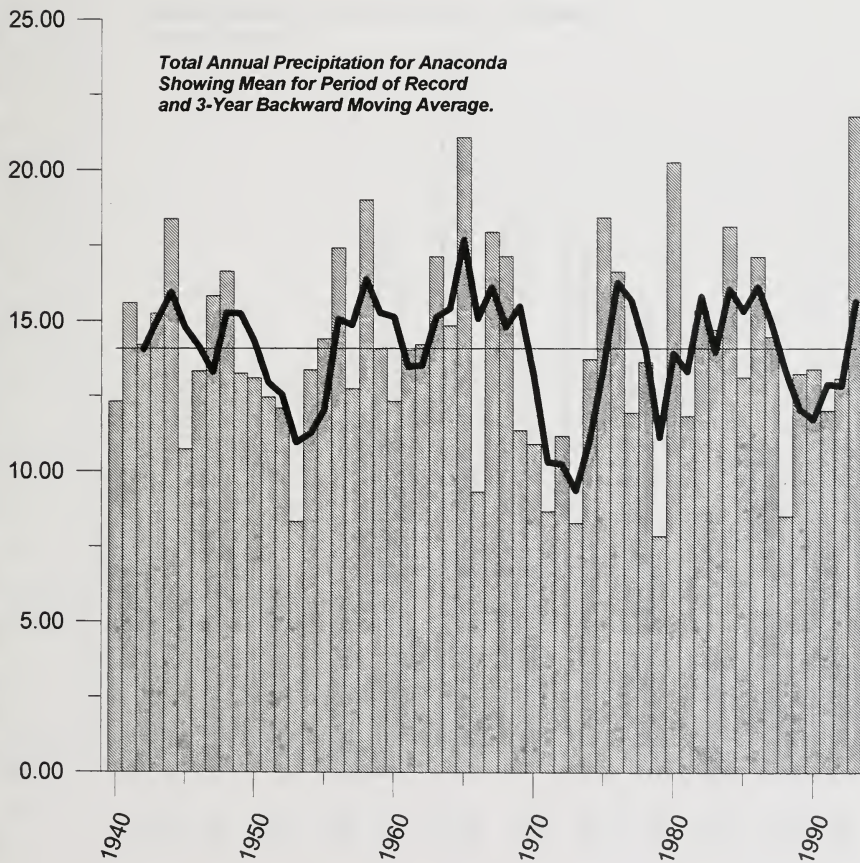
Maximum elevation within drainage basin: 4860 ft

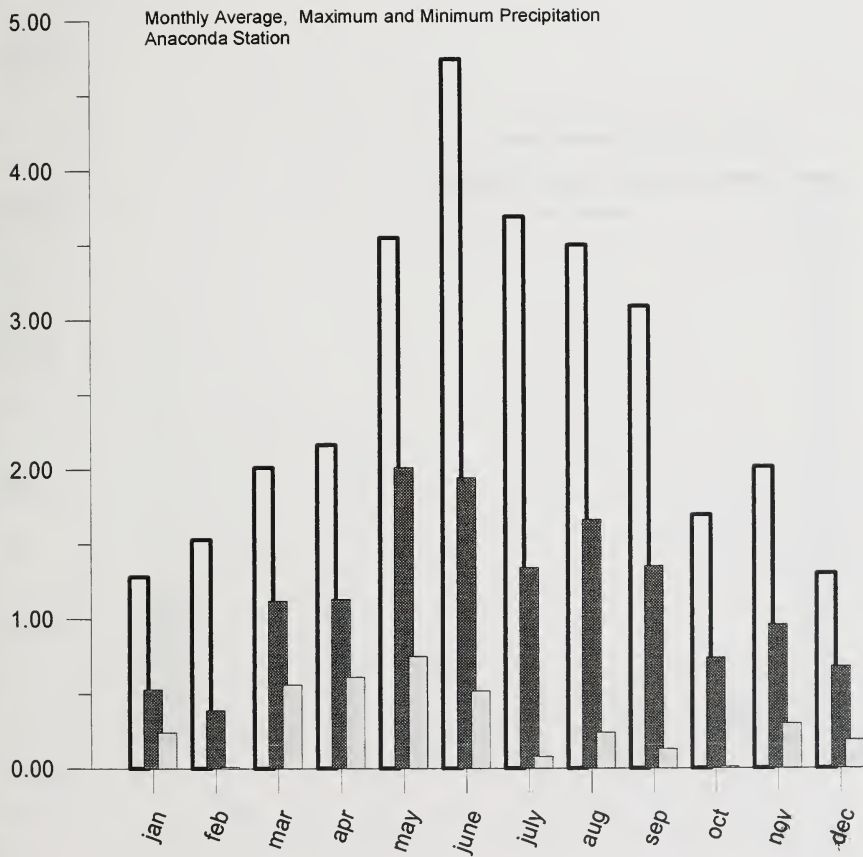
Net relief of contributing basin: 5 ft

COE Hydrogeomorphic class: DEPRESSIONAL

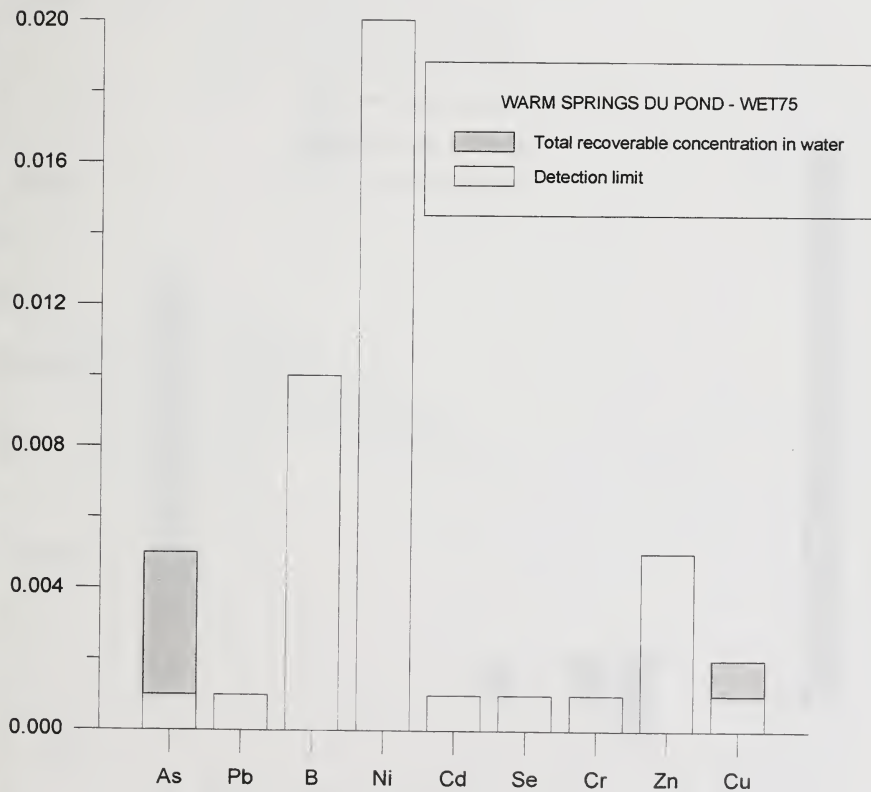
Primary surficial geologic unit 110ALVF

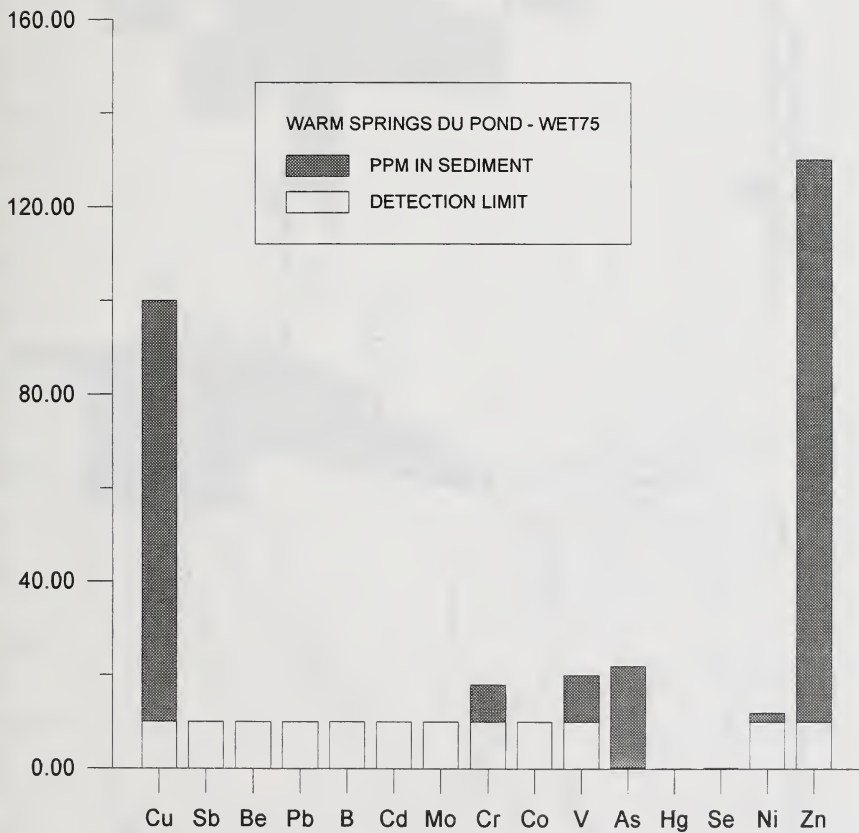
Primary bedrock geologic unit 120SDMS

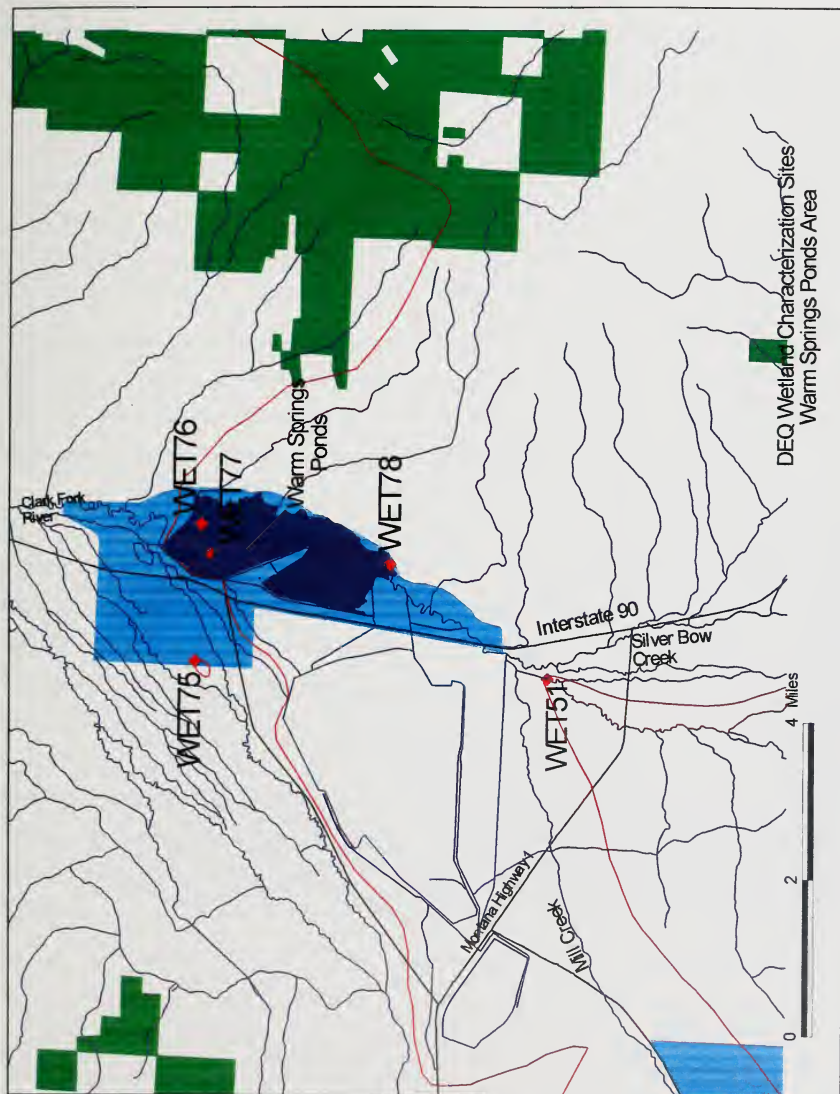




Concentrations in Milligrams per liter







Wetland: WARM SPRINGS POND #1

Site Code: WET76

7.5 Minute Quad: WARM SPRINGS

Lat: 46 10 30

Long: 112 46 10

Mean Annual Precipitation in Inches: 13.00

Mean Annual Potential Evaporation (Penman) in Inches: 33.00

'Net Precipitation' in Inches: -20.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 290 acres

Area of contributing drainage basin: 287800 acres

Mapped elevation of wetland surface: 4860 ft

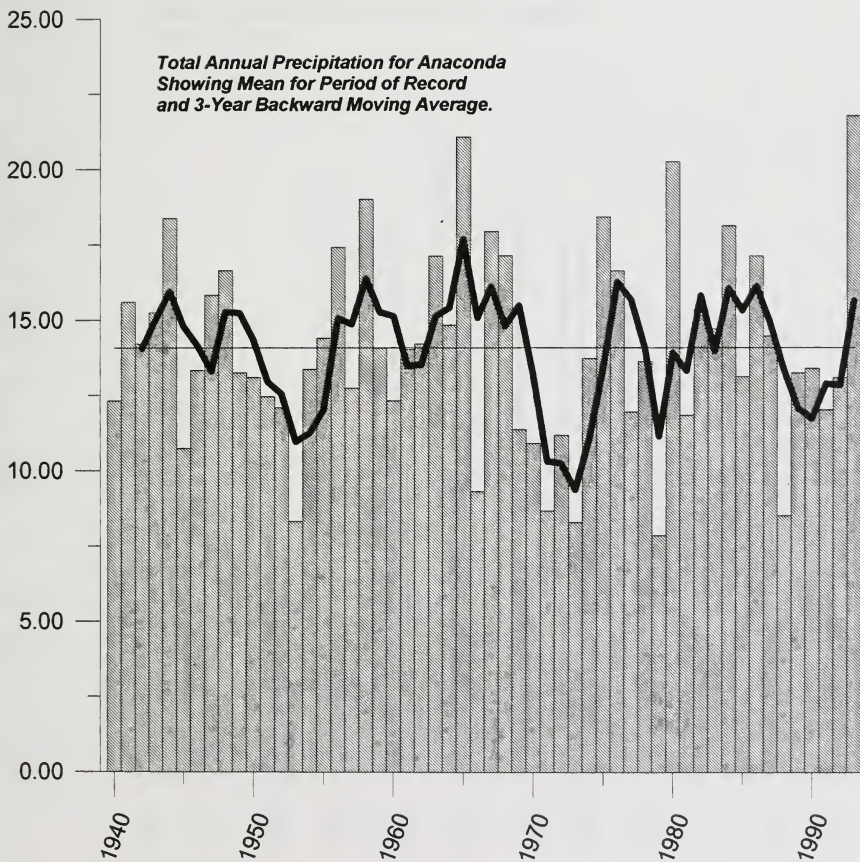
Maximum elevation within drainage basin: 8237 ft

Net relief of contributing basin: 3377 ft

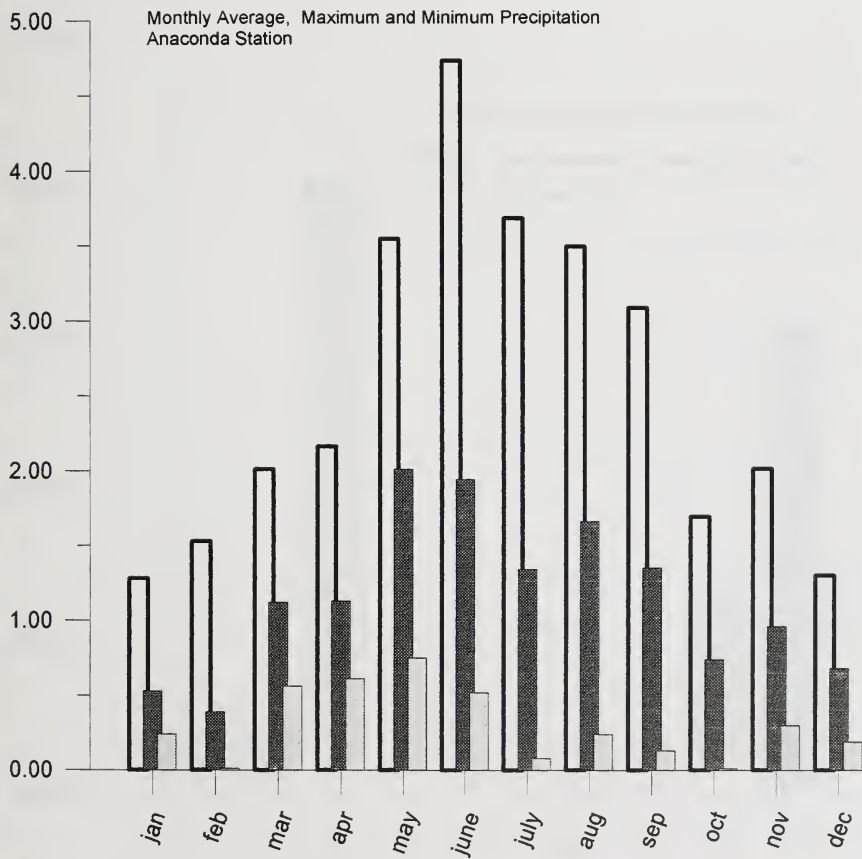
COE Hydrogeomorphic class: DEPRESSIONAL

Primary surficial geologic unit 111MTLG

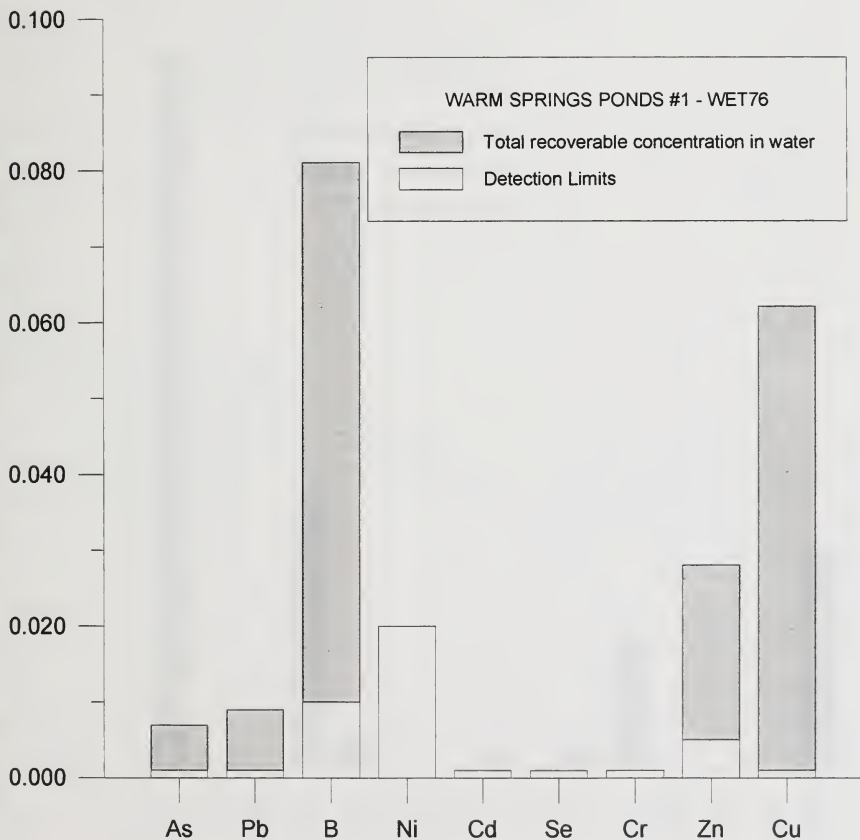
Primary bedrock geologic unit 120SDMS

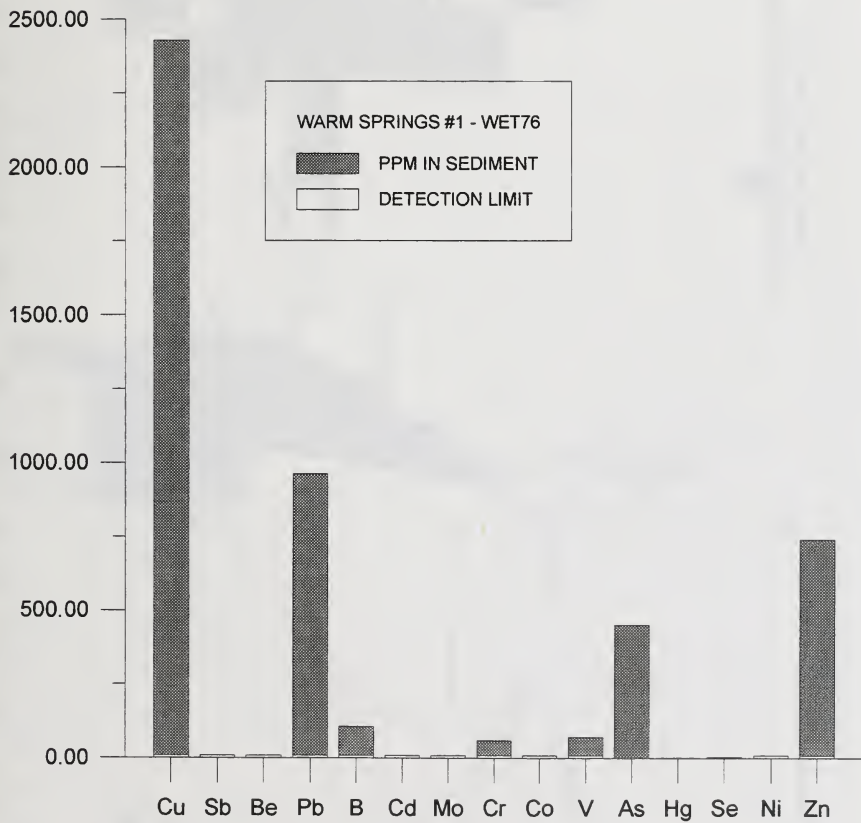


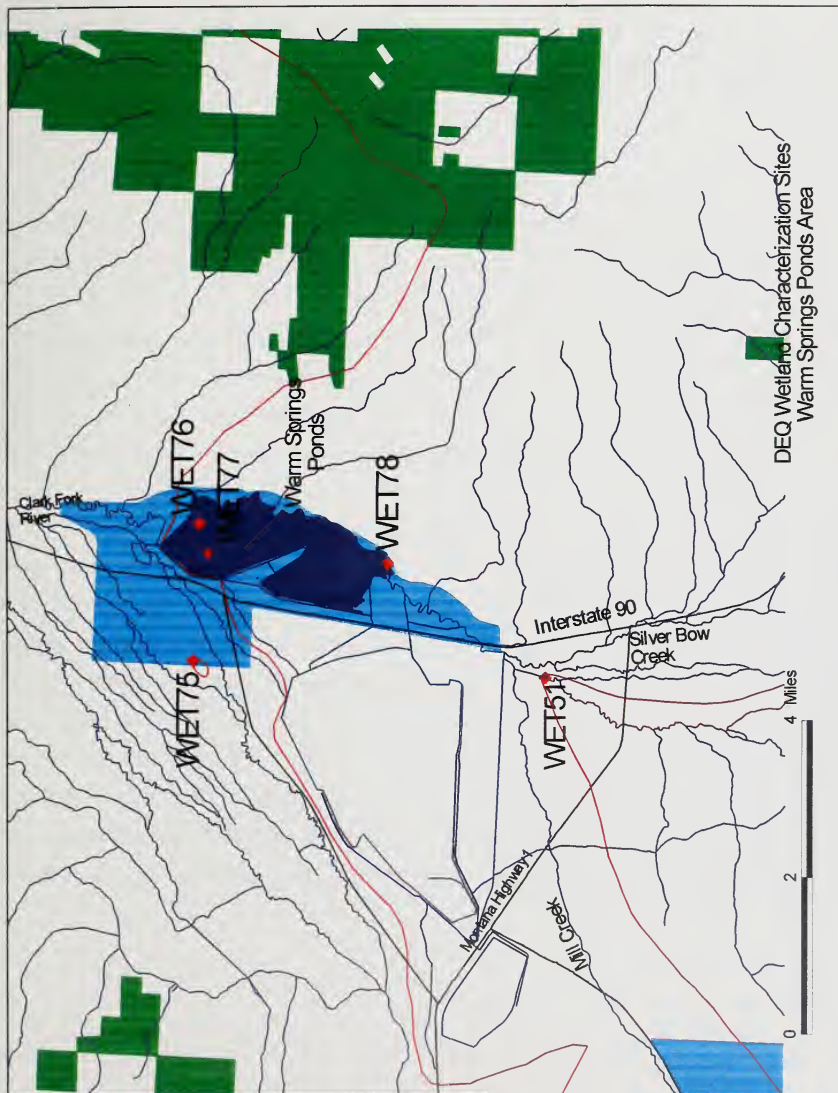
Monthly Average, Maximum and Minimum Precipitation
Anaconda Station



Concentrations in Milligrams per liter







Wetland: WARM SPRINGS POND #2 NEAR OUTLET

Site Code: WET77

7.5 Minute Quad: WARM SPRINGS

Lat: 46 10 25

Long: 112 46 35

Mean Annual Precipitation in Inches: 13.00

Mean Annual Potential Evaporation (Penman) in Inches: 33.00

'Net Precipitation' in Inches: -20.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 525 acres

Area of contributing drainage basin: 287800 acres

Mapped elevation of wetland surface: 4860 ft

Maximum elevation within drainage basin: 8237 ft

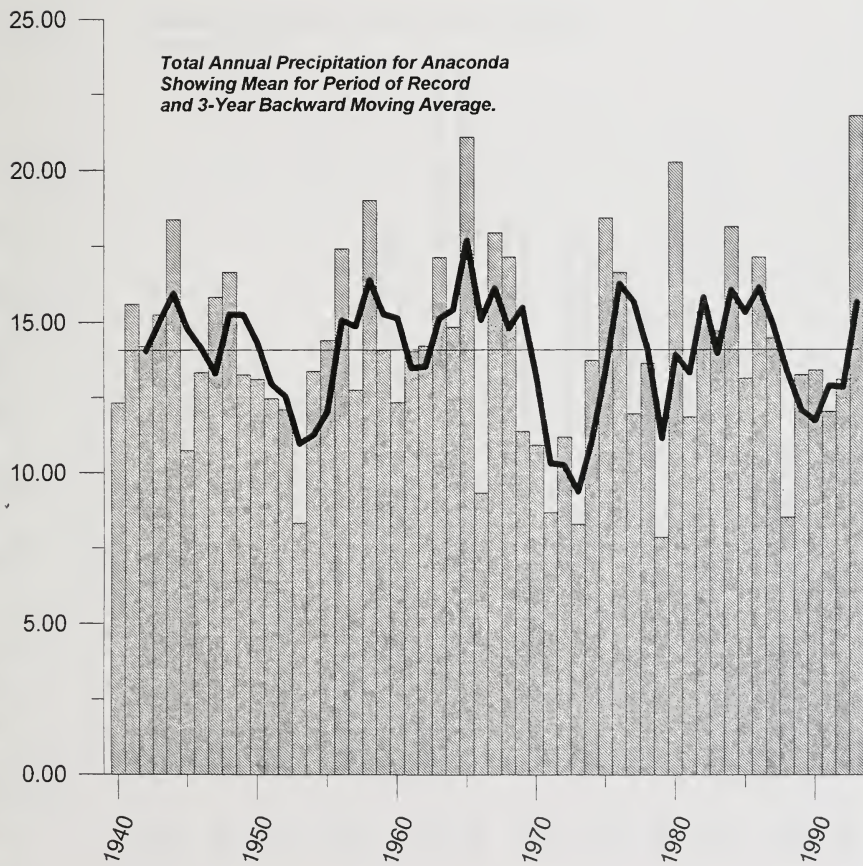
Net relief of contributing basin: 3377 ft

COE Hydrogeomorphic class: DEPRESSIONAL

Primary surficial geologic unit 111MTLG

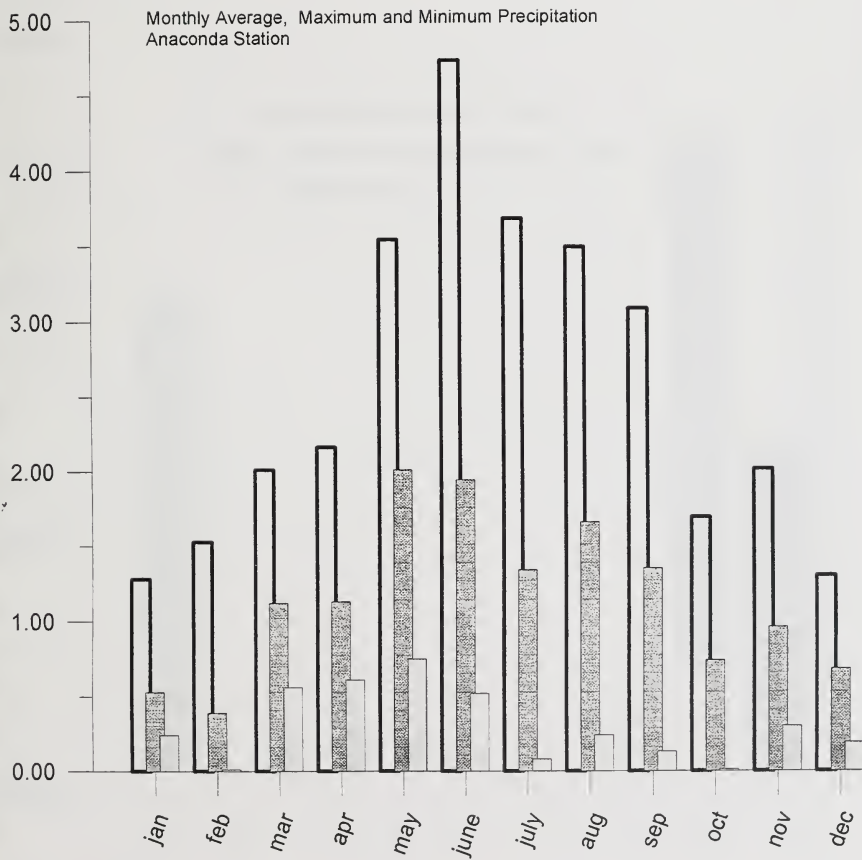
Primary bedrock geologic unit 120SDMS

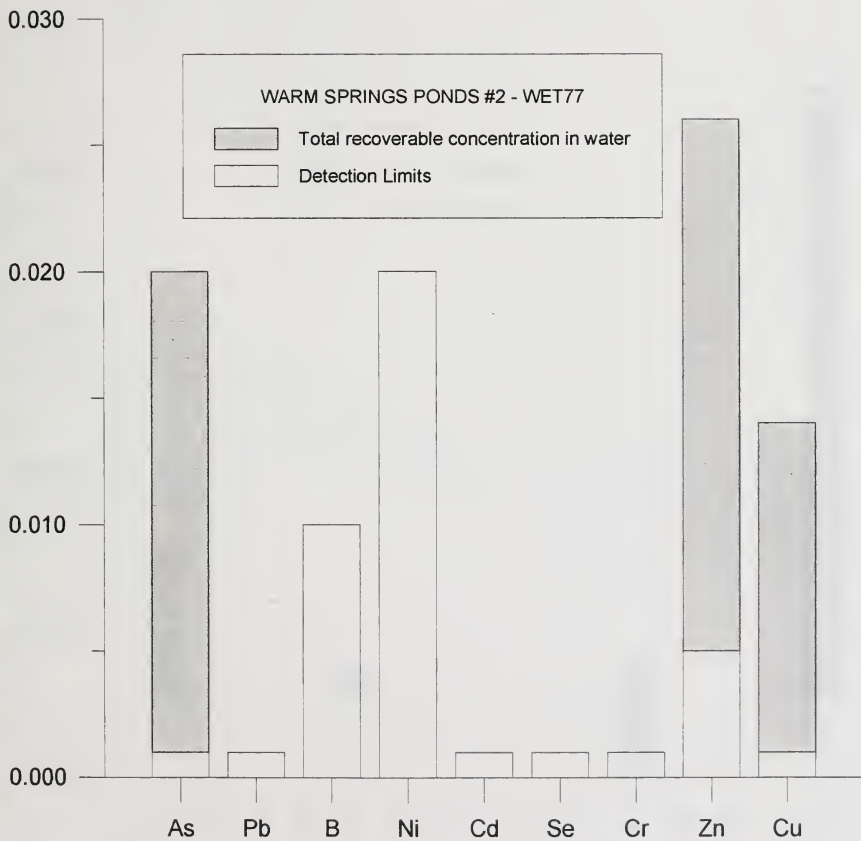
Annual Precipitation in Inches

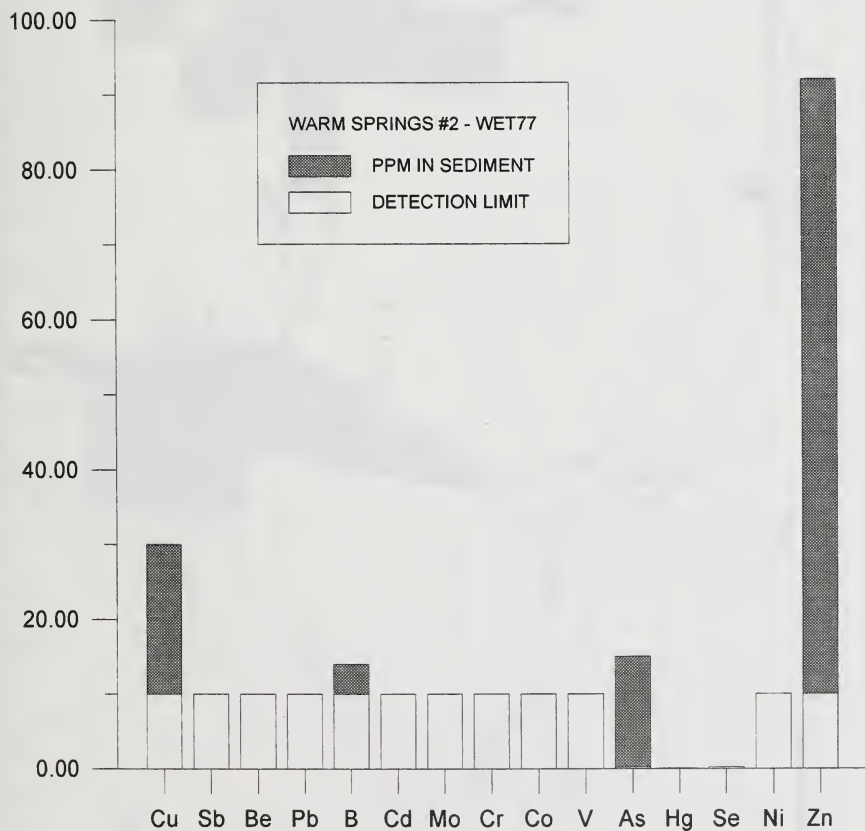


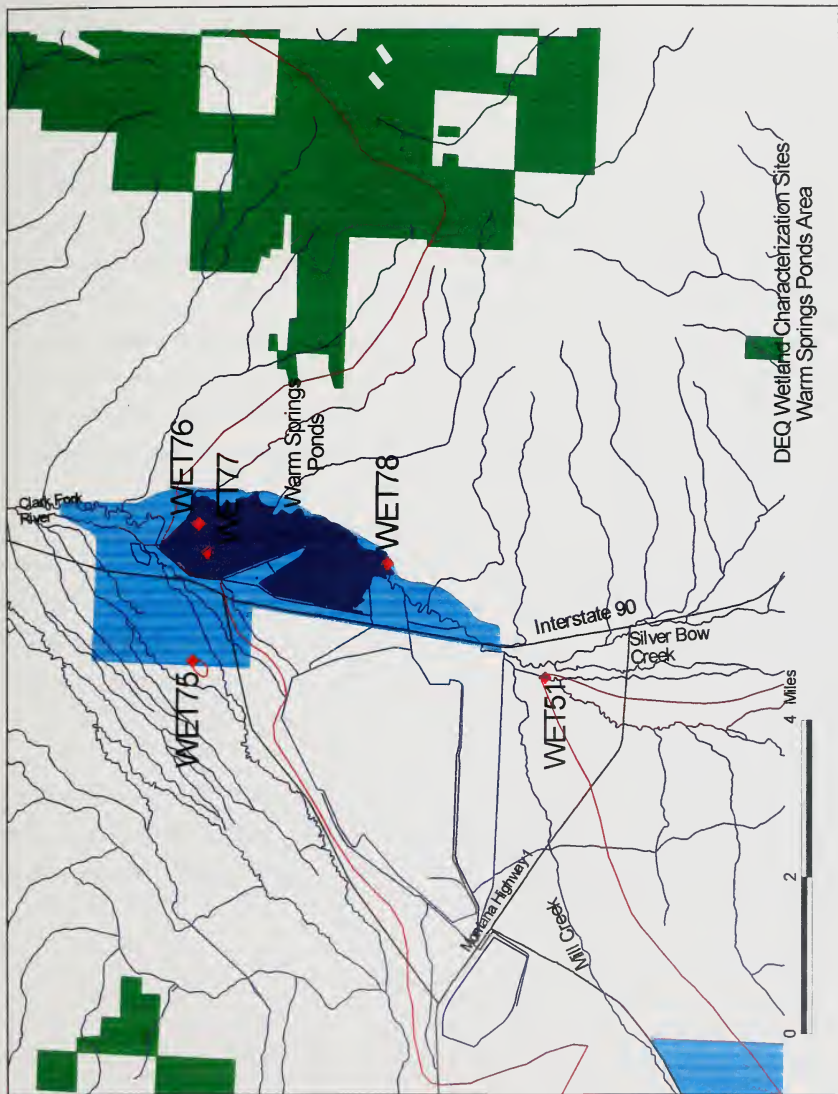
Inches Precipitation

Monthly Average, Maximum and Minimum Precipitation
Anaconda Station









Wetland: WARM SPRINGS POND #3 NEAR INLET

Site Code: WET78

7.5 Minute Quad: WARM SPRINGS

Lat: 46 8 25

Long: 112 46 40

Mean Annual Precipitation in Inches: 13.00

Mean Annual Potential Evaporation (Penman) in Inches: 33.00

'Net Precipitation' in Inches: -20.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 660 acres

Area of contributing drainage basin: 287800 acres

Mapped elevation of wetland surface: 4860 ft

Maximum elevation within drainage basin: 8237 ft

Net relief of contributing basin: 3377 ft

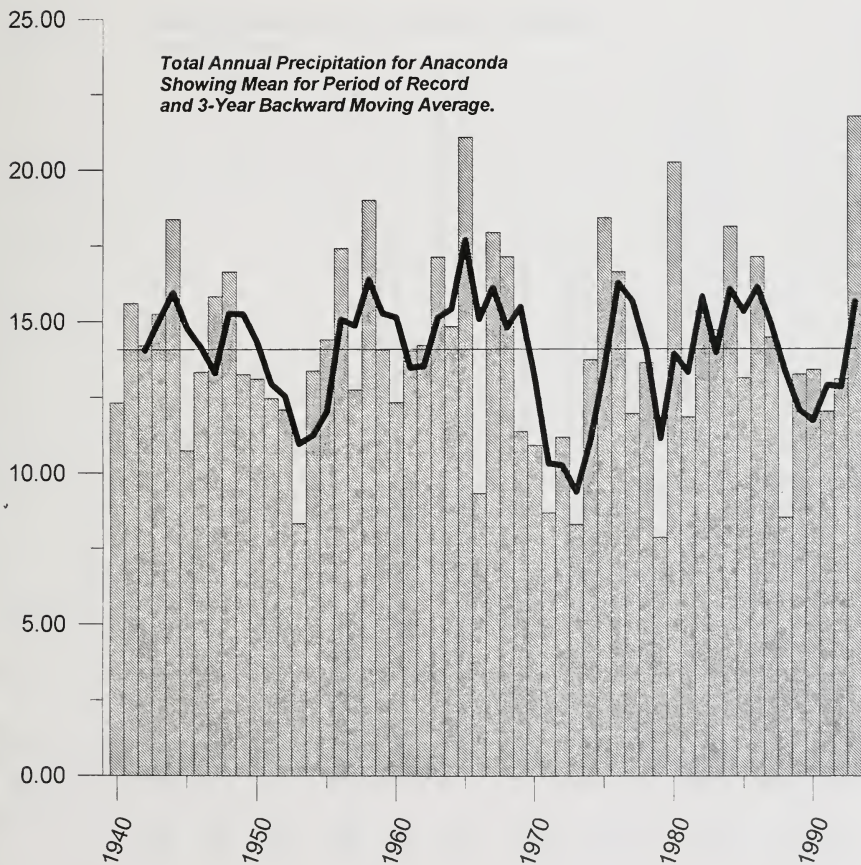
COE Hydrogeomorphic class: RIVERINE

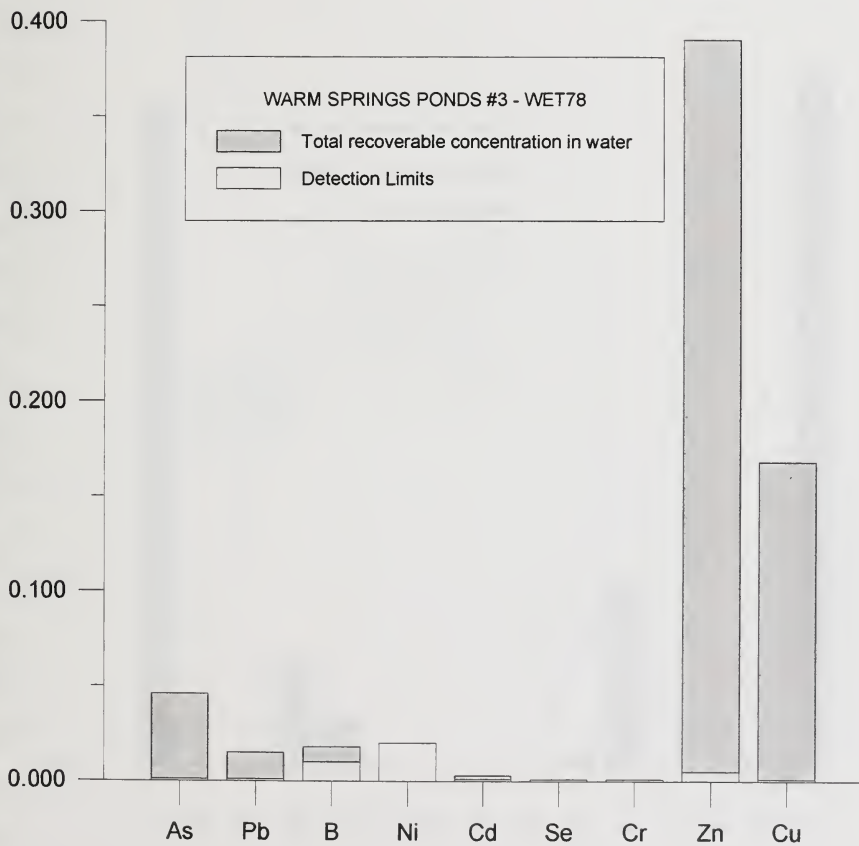
Primary surficial geologic unit 111MTLG

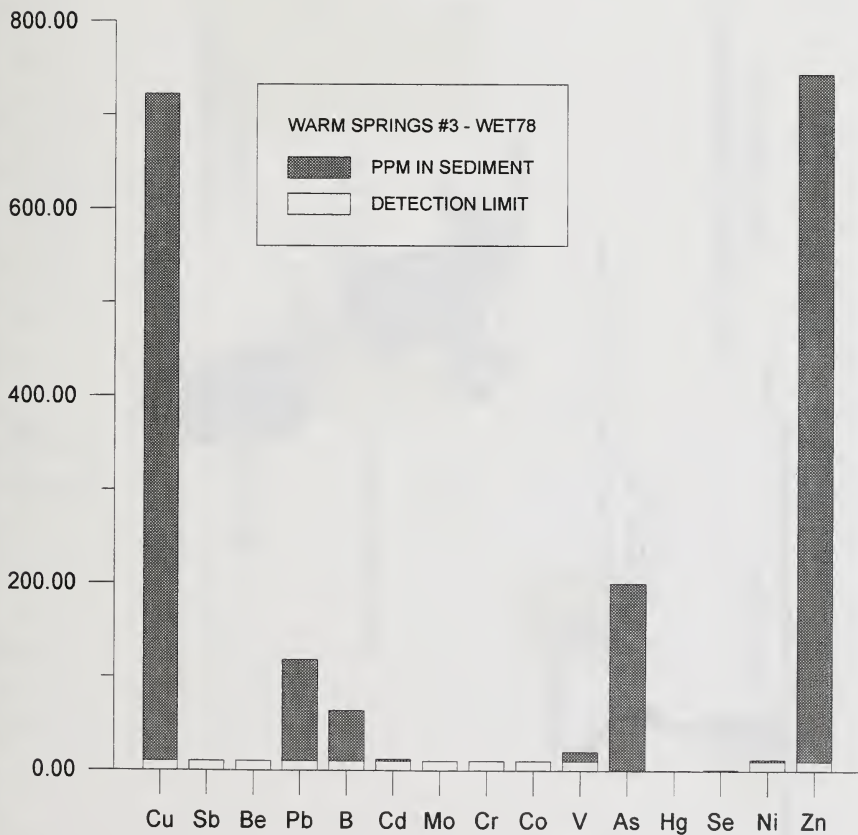
Primary bedrock geologic unit 120SDMS

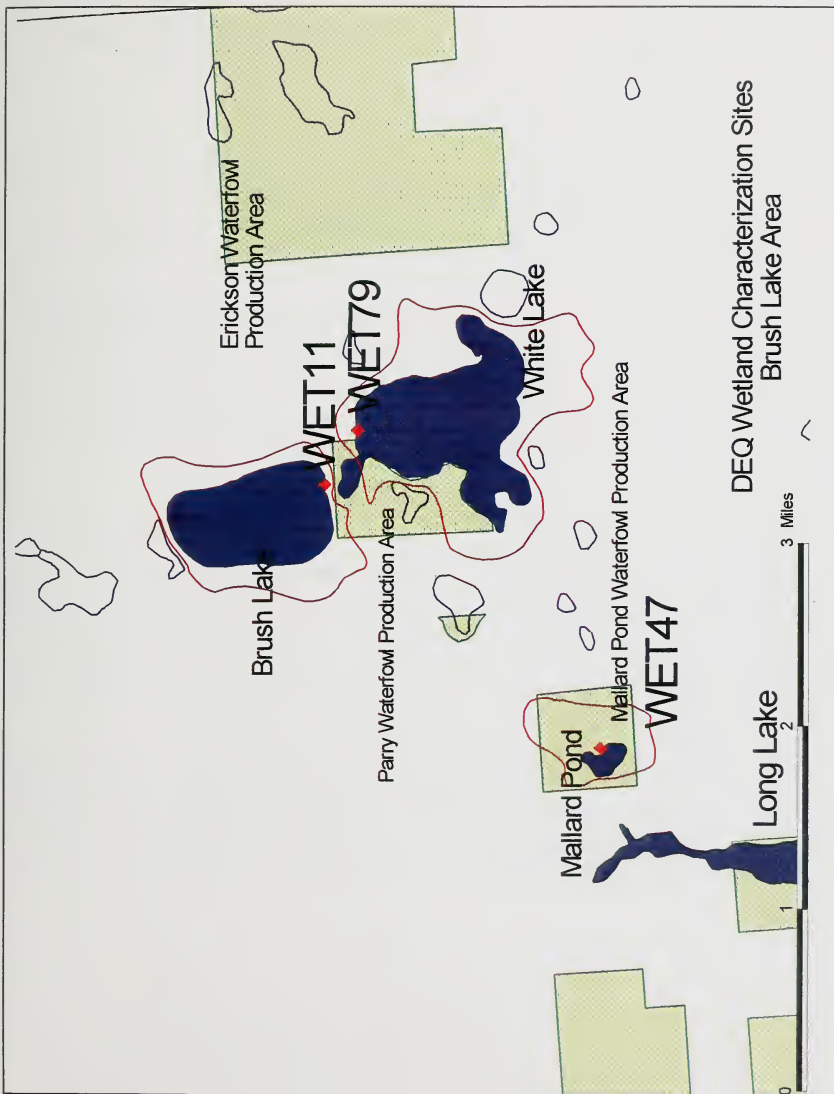
Annual Precipitation in Inches

**Total Annual Precipitation for Anaconda
Showing Mean for Period of Record
and 3-Year Backward Moving Average.**









Wetland: WHITE LAKE

Site Code: WET79

7.5 Minute Quad: BRUSH LAKE

Lat: 48 35 25

Long: 104 5 55

Mean Annual Precipitation in Inches: 13.00

Mean Annual Potential Evaporation (Penman) in Inches: 36.00

'Net Precipitation' in Inches: -23.00

Site does not have a mapped surface inlet.

Site does not have a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 355 acres

Area of contributing drainage basin: 760 acres

Mapped elevation of wetland surface: 1951 ft

Maximum elevation within drainage basin: 2022 ft

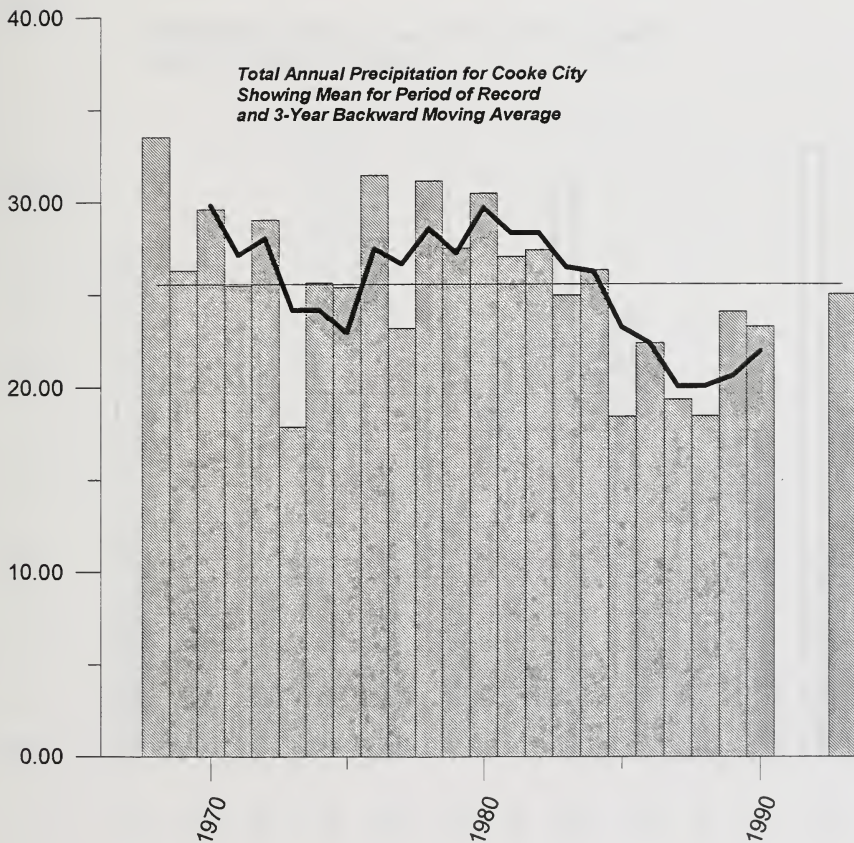
Net relief of contributing basin: 71 ft

COE Hydrogeomorphic class: DEPRESSIONAL

Primary surficial geologic unit 112GLCC

Primary bedrock geologic unit 125FRUN

Annual Precipitation in Inches



8.00

Monthly Mean, Maximum and Minimum Precipitation
Cooke City Station (number)

6.00

4.00

2.00

0.00

jan

feb

mar

apr

may

june

july

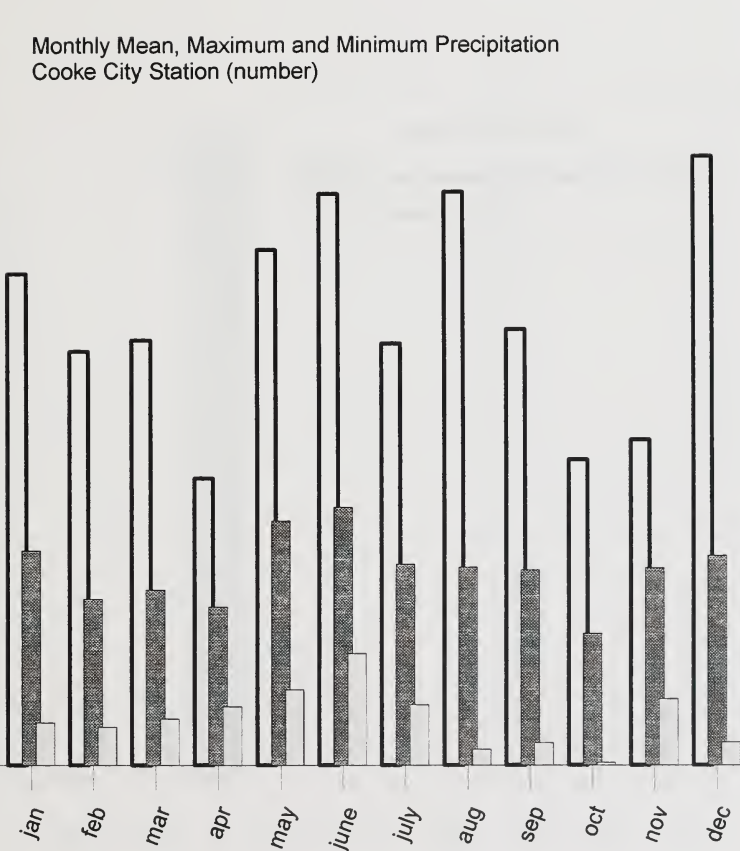
aug

sep

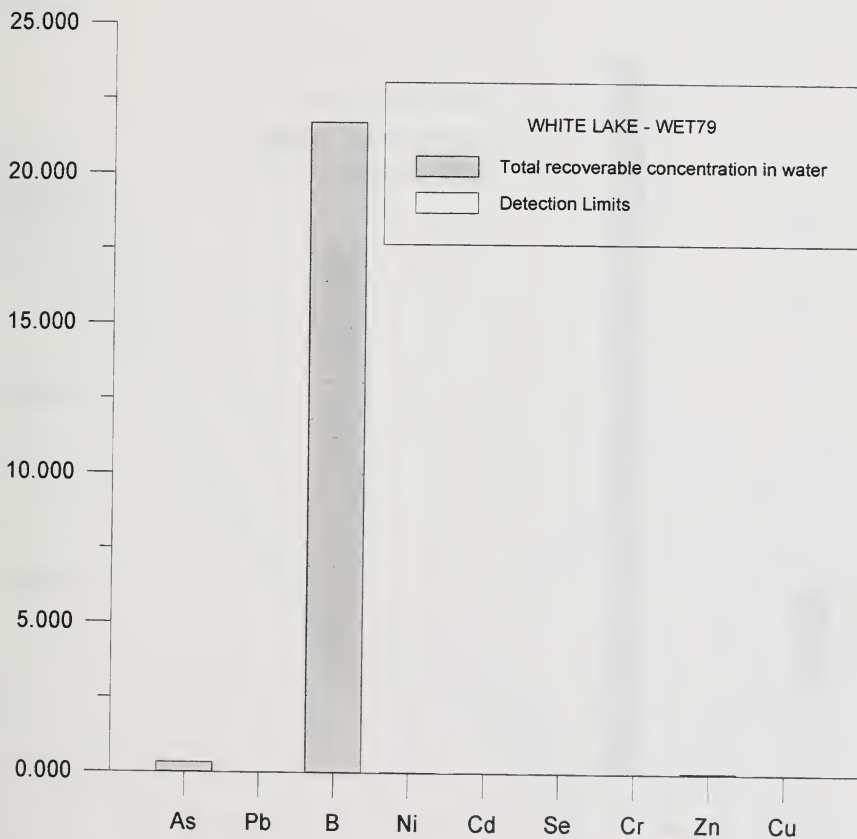
oct

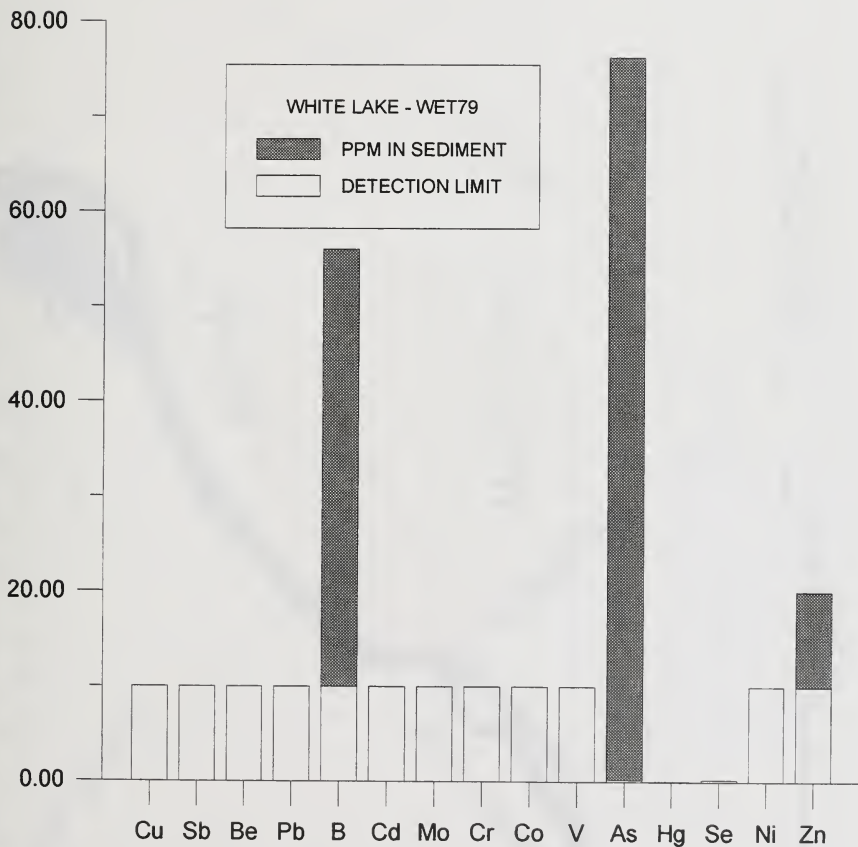
nov

dec



Concentrations in Milligrams per liter







Wetland: YELLOWSTONE RIVER OXBOW AT MILES CITY

Site Code: WET80

7.5 Minute Quad: MILES CITY

Lat: 46 25 25

Long: 105 50 15

Mean Annual Precipitation in Inches: 13.00

Mean Annual Potential Evaporation (Penman) in Inches: 43.00

'Net Precipitation' in Inches: -30.00

Site has a mapped surface inlet.

Site has a mapped surface outlet.

Site is not known to be artificially impounded.

Site does not have known significant water imports.

Mapped area of wetland: 4 acres

Area of contributing drainage basin: 450 acres

Mapped elevation of wetland surface: 2338 ft

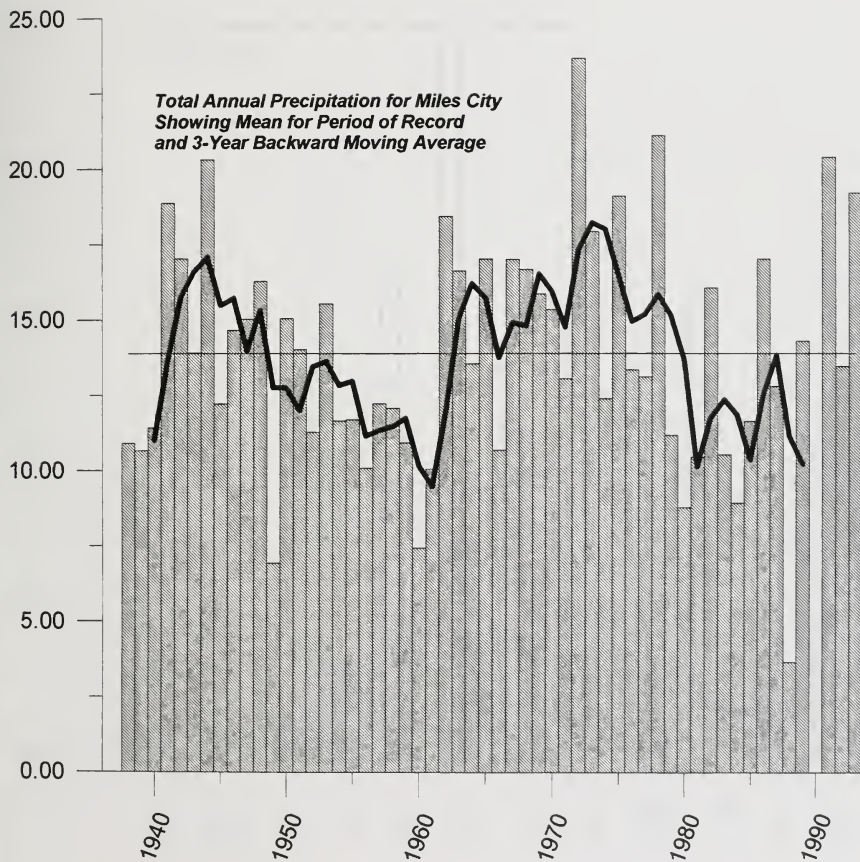
Maximum elevation within drainage basin: 2400 ft

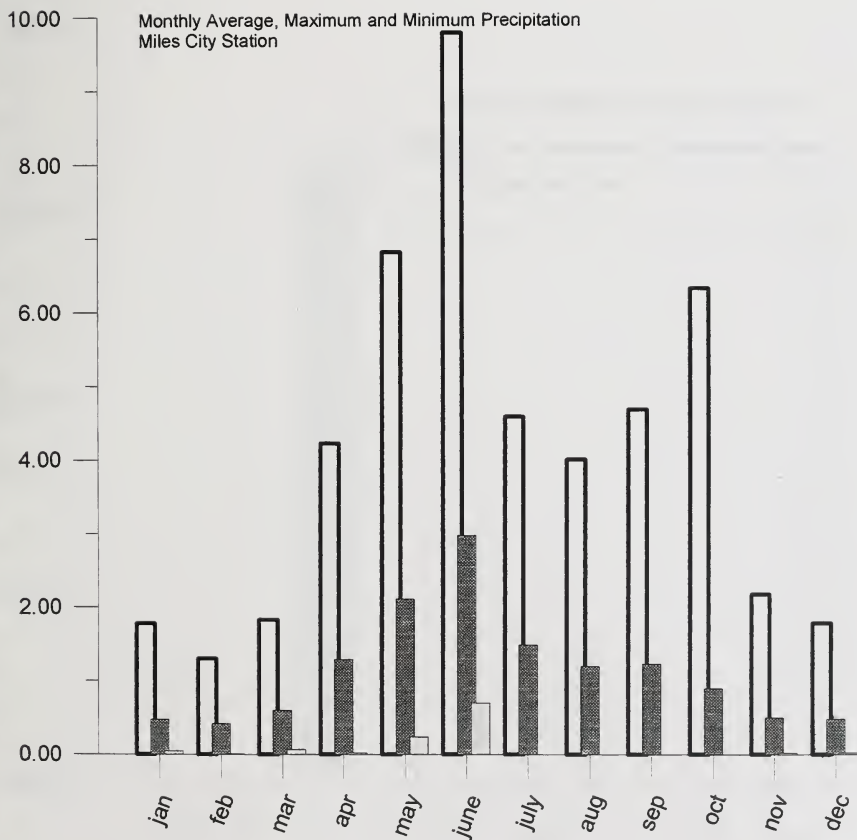
Net relief of contributing basin: 62 ft

COE Hydrogeomorphic class: DEPRESSIONAL

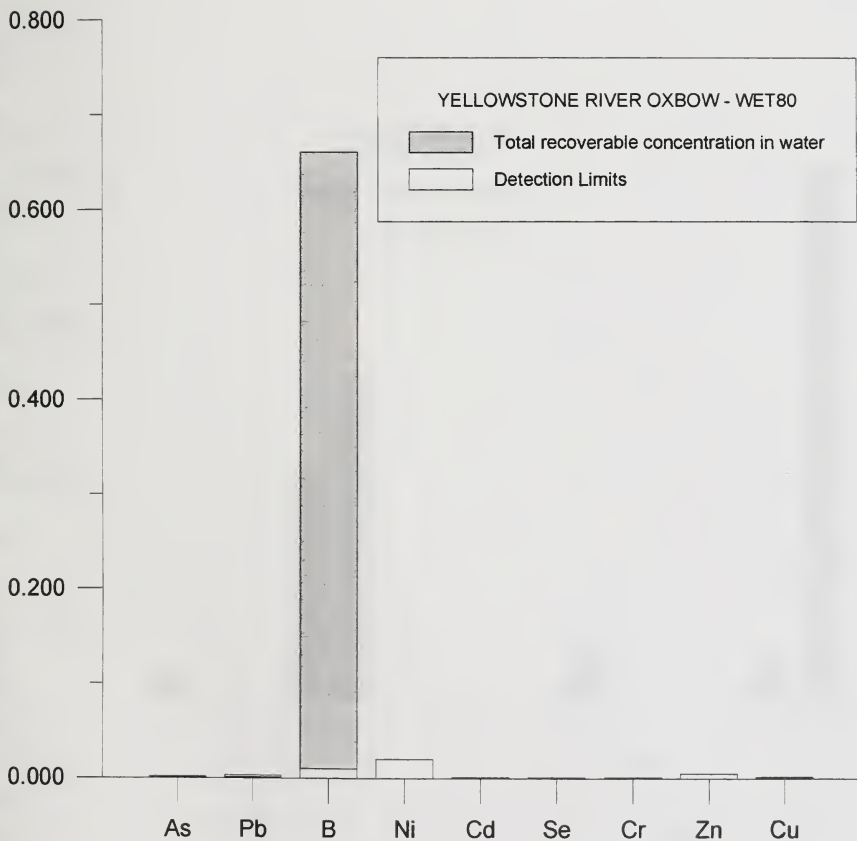
Primary surficial geologic unit 111ALVM

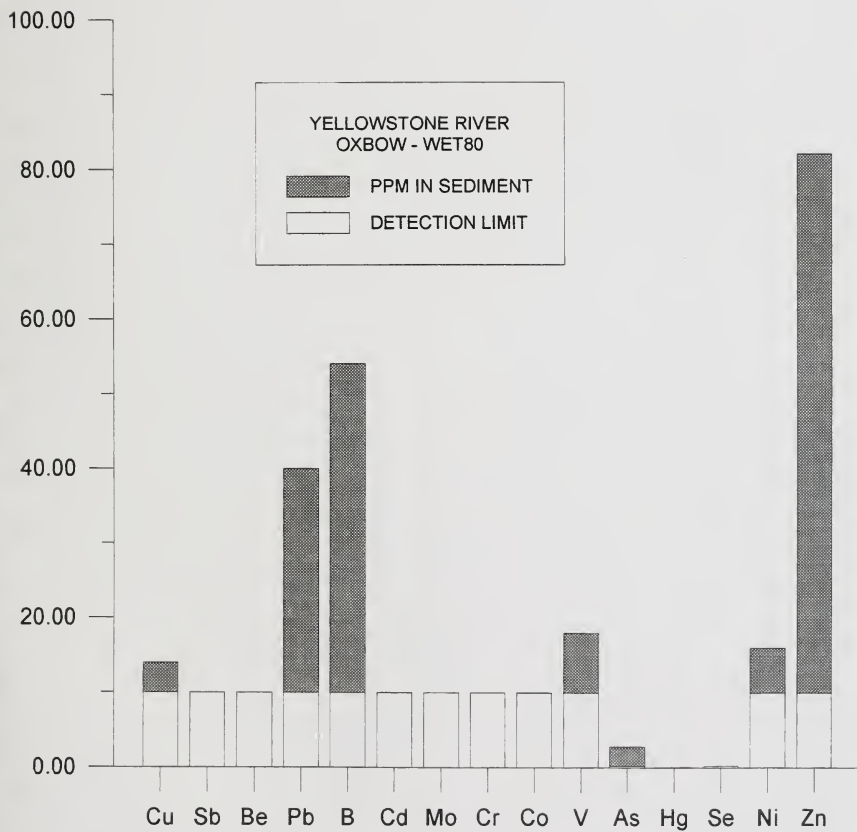
Primary bedrock geologic unit 125FRUN



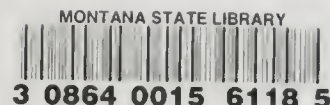


Concentrations in Milligrams per liter





S
551.41
N11ggc
1995
Appendix B



Geologic, Geomorphic and Chemical Characteristics of Wetlands Selected for Use in Biocriteria Development by the Montana Department of Environmental Quality

by

Mark D. Shapley
Montana Natural Heritage Program
1515 East 6th Avenue
Helena, MT 59620

for the

Montana Department of Environmental Quality
Water Quality Division

December, 1995

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HELENA, MONTANA 59620

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Appendix B.

Narrative Summaries of the Physical Setting and Chemical Characteristics of the DEQ Wetland Characterization Sites

Alkali Lake

Climatic setting. The net annual precipitation balance for Alkali Lake (from the MAPS database) is approximately -13 inches. This places the site toward the less evaporative end of the climatic spectrum for closed basin sites, but near the more evaporative extreme for Rocky Mountain sample sites. Monthly average precipitation for the Fortine climatic station shows relatively even distribution throughout the year, with a moderate peak in May and June. Annual records from the Fortine station show the 3-year running average precipitation has been below the long-term mean during most of the last 30 years. Annual precipitation during the sample year of 1993 exceeded the average for the period of record by approximately 5 inches.

Geologic setting. The Alkali Lake basin is underlain by calcareous till and possibly other glacial sediment types of late(?) Wisconsin age. Shorelines are composed of coarse-grained sediments in high energy areas, marly mud in deeper water and sheltered littoral areas. Bedrock geologic units are of the Proterozoic Belt Series, probably including the calcareous and dolomitic Helena Formation.

Hydrologic type. Alkali Lake is a glacial depression lacking surface drainage at current water levels. Strandlines represented by tree kills indicate historic water levels within the past few decades which would have allowed surface discharge. Groundwater outflow is inferred from moderate salinity of this topographically closed basin.

Basin characteristics. Alkali Lake has a small surface catchment with respect to lake area and volume. The basin is linear and shallow at both ends, with a maximum measured depth in mid-basin of 37 feet. The cluster of lakes in the vicinity display disjunct water quality; Thirsty Lake, nearby and at a lower elevation, exceeds Alkali Lake in specific conductance by more than an order of magnitude. Road construction has partially isolated the eastern arm of the lake during high-water conditions.

Water chemistry. Alkali Lake is proportionately high in magnesium and is almost completely depleted in calcium; low calcium concentrations appear to be maintained by solubility controls, evidenced by deposition of authigenic carbonate minerals. High relative magnesium concentrations are typical of hydrologically similar sample sites. Equilibrium calculations indicate supersaturation with calcium and magnesium carbonate species.

In comparison to hydrologically similar sample sites, Alkali Lake exhibits relatively low water-column concentrations of trace elements. Total organic carbon concentrations are at the high end for the region and for hydrologically similar sites.

Chemical history. Specific conductance measurements from 1968 were

approximately 25% lower than 1993 and 1994 measurements. Seasonal measurements in 1993 and 1994 show approximately 10% difference in salinity. Vegetation indicators show considerably higher lake volume within the past few decades, implying significantly more dilute water chemistry. The measured salinity range within the lake basin was minor, amounting to approximately 5% in specific conductance.

Sediments. Sediment trace element concentrations are generally low with respect to regionally and hydrologically similar sample sites. Trace elements found above detection limits (arsenic, boron, copper and zinc) occurred at concentrations below the regional mean soil concentrations for these parameters (Shacklette and Boerngen, 1984).

Bandy Reservoir

Climatic setting. The net annual precipitation balance for the Bandy Reservoir site (from the MAPS database) is -15 inches, placing the site toward the more humid end of the range for hydrologically and regionally similar sites. Monthly average precipitation for the Ovando 9 SSE climatic station shows a bimodal distribution, with a primary June peak and a secondary January peak. The 3-year moving average of total annual precipitation remained below (often considerably below) the long-term average from the mid-1970s through 1993. The total precipitation for 1993 (the year prior to sampling) was very near the long-term average.

Geologic setting. Bandy Reservoir is underlain by calcareous late Pleistocene till deposited by ice advancing down Monture Creek from sources in the Swan Range. Bandy Reservoir lies along the kettle-pocked lateral moraine marking the westward extent of the Monture advance. The till is described as variable in texture and may overlie glacial deposits (including outwash) deposited by the slightly earlier Clearwater glacial advance. Fine-grained Tertiary aged valley fill deposits underlie glacial deposits at unknown (but probably shallow) depths.

Bedrock geologic units in the source area for sediments deposited by the Monture advance include several distinct formations of the Proterozoic-aged Belt series; large areas are underlain by the calcareous and dolomitic Helena Formation.

Hydrologic type. Bandy Reservoir is an artificial impoundment of a natural basin that probably had a prior history as a smaller natural water body. Presently it provides off-stream storage of water diverted from Shanley Creek. Discharge is back to Shanley Creek (and to local irrigated areas?). Water levels are manipulated for irrigation storage purposes, and probably do not reflect natural water level fluctuations of unmanipulated nearby lakes.

Basin characteristics. The natural (closed) catchment of Bandy Reservoir is small and probably supported only a minor (perhaps seasonal) pond or wetland similar to many others along the Monture moraine. As a reservoir, it receives inflow from a large catchment and has a relatively high catchment to wetland area ratio. Diversion rates and lake volume are unknown, but the flux of water through the reservoir is probably relatively rapid.

Water chemistry. At the time of sampling, Bandy Reservoir contained dilute ("fresh") but highly alkaline calcium-magnesium/carbonate water. Equilibrium calculations indicate oversaturation with carbonate species at the sampled pH. Phosphorous, nitrogen and total organic carbon concentrations were near the low end of the ranges for hydrologically and regionally similar sites. Most trace element concentrations were below detection limits. Arsenic and copper were found at concentrations

near the low end of ranges for similar sites.

Chemical history. No chemical data other than those from the DHES sampling are known for Bandy Reservoir. It is reasonable to infer that flushing with dilute, high-quality water from Shanley Creek maintains dissolved constituents within a relatively narrow range. Prior to hydrologic manipulation, the basin may have developed somewhat more saline water similar to nearby closed ponds and wetlands.

Sediments. Arsenic, boron, copper and zinc were found at low to mid-range concentrations in comparison to hydrologically similar sites. Selenium and mercury were reported at their respective detection limits; values for both elements approximate mean concentrations in soil and other surficial material of the western U.S..

Beaver Creek Wetland

Climatic setting. The net annual precipitation balance for the Beaver Creek site (from the MAPS database) is -6 inches, placing the site near mid-range in evaporative intensity for Rocky Mountain sample sites. [At absolute values in this range, the "annual precipitation balance" should definitely be considered only a relative scaler of evaporative intensity, not an indicator of the true sign of the site's moisture balance.] Mean monthly precipitation for the Seeley Lake Ranger Station climatic station shows a bimodal distribution with the primary peak in January and a secondary June maximum. The 3-year running average at Seeley Lake shows an apparent periodicity in annual precipitation, with a period of five to six years. Since the early 1970's, the three-year average has been mainly below the average for the period of record. Total precipitation in 1993 (the year prior to sampling) was about 3 inches below average.

Geologic setting. The Beaver Creek site is underlain by till (and other glacial sediments?) deposited by the late Pleistocene advance of glacial ice down Placid Creek. The texture of the till in the general area is described as sandy; soil drainage, however, is described as poor. Bedrock formations underlying the area inferred to have contributed glacial sediments to the site include mainly noncalcareous formations of the late Proterozoic Belt series.

Hydrologic type. The Beaver Creek wetland is an apparent kettle lacking discrete surface water inflow or outflow. Mineral equilibria (see below) may reflect either a ground-water recharge position for this site, or a lack of carbonate lithologies in local geologic materials.

Basin characteristics. The WET03 site is one of a cluster of poorly integrated depressions forming a stepwise profile across an interfluvial plateau. Ground-water flow between depressions is inferred from the lack of surface drainage and dilute water quality of the sample site. The calculated ratio of catchment to wetland area is toward the higher end for sites included in this type; the surface catchment used, however, does not discriminate small internally drained areas and so may not be meaningful to the hydrology of the wetland site. Road construction may have altered drainage from this wetland.

Water chemistry. The Beaver Creek wetland displays very dilute calcium bicarbonate chemistry. The measured total dissolved solids concentration was among the lowest in the sample set. Mineral equilibria indicate substantial undersaturation with carbonate species. Phosphorous concentrations were near the low end of the range for all sample sites, nitrate was below detection limits, and the ammonium concentration was mid-range for hydrologically similar sites. The total organic carbon concentration was among the upper 50% of hydrologically similar sample sites.

Most trace elements were below detection limits; the copper concentration was mid-range among hydrologically similar sample sites.

Chemical history. No chemical data other than that provided by the DHES sampling are known for this site.

Sediments. Extractable concentrations of most trace elements are below detection limits or well within the range for hydrologically similar sites. Selenium and nickel were found near the high end of their ranges for similar sites. Mercury was reported at the detection limit. Copper, nickel, boron and mercury concentrations approximated mean values for soils and other surficial materials in the western U.S. Selenium exceeded the western U.S. mean by a factor of about 2.

Bent Flat Fen Proposed RNA

Climatic setting. The net annual precipitation balance for the Bent Flat fen (from the MAPS database) is -4 inches, placing this wetland toward the middle of the range shown by Rocky Mountain sites. Mean monthly precipitation values for the Hungry Horse Dam climatic station shows a bimodal distribution with June and January peaks. The recent record for this climatic station is fragmentary; annual totals for 1991 and 1992 were below average for the period of record.

Geologic setting. Bent Flat is a calcareous fen underlain by 2 meters or less of peat and organic-rich marl. The fen sediments are deposited over a surface of dense, clay-rich till. Active precipitation of carbonate minerals occurs in a complex of pools, channels and vegetation mats forming string-and-flark patterning approximately along the topographic contour of the fen surface. The fen is supported by ground-water discharge from upland springs within a few hundred meters upgradient. Adjacent upland slopes are underlain by tufa and travertine deposited by these springs.

The springs are believed to represent ground-water discharge from Cambrian limestones underlying slopes and peaks to the east and northeast.

Hydrologic type. Bent Flat is a patterned fen (unusual in Montana) with inflow provided by short streams fed by nearby ground-water discharge. Outflow occurs by a peripheral stream and by channelized outflow from the toe of the wetland.

Basin characteristics. Ground-water supporting the Bent Flat fen is recharged over an unknown area. Flow within the fen is complex, following convoluted surface pathways through interconnected pools (flarks) and moving as shallow groundwater flow through the vegetation mat. The fen is developed on a low-gradient slope at the base of a steep glaciated ridge. Where examined, the hydraulic conductivity of the underlying glacial materials appears to be low.

Water chemistry. Bent Flat Fen contains relatively dilute, mildly alkaline calcium-bicarbonate water which actively precipitates calcite as it moves from the ground-water environment to the fen. Saturation with calcium carbonate phases is shown by the ubiquitous deposition of authigenic calcite (and/or aragonite?) around the outlet springs and within the fen. Deposition may be seasonal, as equilibrium calculations indicate slight calcite undersaturation under cold (3 degrees C) temperatures.

Nitrogen (nitrate plus ammonium) concentrations rank in the upper third among hydrologically similar sites; phosphorous concentrations are near the lower end of the range. The total organic carbon concentration at the time of sampling was toward the upper end of the range shown by hydrologically similar sample sites.

Chemical history. Prior to the DHES sampling, two water quality samples were collected from Bent Flat in November of 1993. One sample came from the immediate area of the springs supplying the fen. The other was collected from near the lower end of the fen, bracketing the WET04 site. Generally, major ion chemistry varied little between the three samples; the springs probably provide quite stable inlet water chemistry. Minor differences should be expected due to dilution and concentration effects and possibly because of changing rates of carbonate precipitation.

Nutrients, however, are more directly tied to biological activity within the fen and appear to show important spatial and seasonal variability. In November of 1993, nitrate and ammonium concentrations both decreased substantially (and disproportionately to minor dilution effects) between the inlet and lower fen sites, while total phosphorous and total organic carbon concentrations increased by factors of four and five respectively. In September 1994, the WET04 site showed total phosphorous and TOC concentrations respectively seven and ten times higher than the lower fen site of November 1993.

Sediments. An exceptionally high concentration of extractable calcium (24%) reflects the marly nature of Bent Flat sediments. Arsenic, boron, mercury, selenium and zinc occurred in detectable concentrations in the sample of Bent Flat sediment. All were found at low concentrations in comparison to the rest of the data set, with the exception of mercury and selenium. The reported mercury concentration was slightly above the western U.S. mean for soils and other surficial materials, and the selenium concentration exceeded the western U.S. mean by a factor of about 2.

Benton Lake National Wildlife Refuge

Climatic setting. The net annual precipitation balance for Benton Lake (from the MAPS database) is -27 inches, placing the site toward the more evaporative end of the range for its class. Average monthly precipitation for the Great Falls Airport climatic station shows a strong May-June peak. Between 1980 and 1993, the three-year running average of annual precipitation remained near the mean for the period of record, despite several extreme years. In 1993 (the year of sampling), annual precipitation exceeded the average by more than 7 inches. The 1992 total was about 2.5 inches below average.

Geologic setting. Benton Lake is underlain by a thick sequence of glaciolacustrine sediments deposited in Glacial Lake Great Falls during late Pleistocene time. Glacial Lake Great Falls sediments in the Benton Lake basin are described as composed dominantly of plastic clay. Till and other surficial materials underlie other portions of the catchment. Underlying pre-Quaternary formations include the Marias River Shale and the Blackleaf Formation.

Hydrologic type. Benton Lake is a highly managed system relying on pumped importation of water from Muddy Creek. There is no surface water outflow and due to topographic position and geologic characteristics, no likelihood of significant ground-water outflow. A large fraction of the Muddy Creek water delivered to Benton Lake consists of irrigation return flows from the Greenfields Division of the Sun River Irrigation Project.

Basin characteristics. The catchment to wetland area ratio for Benton Lake is toward the low end of the range for the sample set. However, Benton Lake inflows are managed by manipulation of imports from Muddy Creek. Benton Lake itself is subdivided by dikes into six separate pools with sequentially lower interconnecting spillways from the inlet pool to the southeastern end of the lake. Salinity and disease management involves flooding only some of the pools during any given year, while others stand dry.

Water chemistry. At the time of sampling in August 1993, Benton Lake Pool #1 contained alkaline, "oligosaline" water of mixed cation/sulfate chemistry. Mineral equilibria indicate oversaturation with carbonate phases and moderate undersaturation with respect to gypsum. The nitrate concentration was very high, while phosphorous (total and orthophosphate) and total organic carbon concentrations were toward the low end of the range for the wetland type and region. The water column selenium concentration was the highest of the five sample sites for which detectable selenium was reported. WET05 was also among the five sites with detectable nickel reported from the water column. The reported arsenic concentration was among the lowest for the sample sites.

Chemical history. Monitoring programs of the U.S. Fish and Wildlife Service and the USGS have generated an intensive (if

brief) water quality data set for Benton Lake. Since 1990, specific conductance in pond #1 has varied across more than an order of magnitude, with a maximum reported concentration of 10920 microsiemens/cm. Three reported selenium concentrations ranged from .001 to .011 mg/l. Spatial variability within the Benton Lake complex can also be substantial. Synoptic sampling in August of 1986 showed pool #5 (the southeastern quadrant of the lake) to have specific conductance approximately four times higher than pool #1; reported boron concentrations were higher in pool #5 by a factor of about 3, and arsenic was reported from pool #5 at 63 times the concentration reported for pool #1.

Sediments. The WET05 site exhibited the highest sampled concentration of nickel and the highest zinc and second highest selenium concentrations for a site in it's classification. WET05 was one of only five sites with a reported (barely) detectable concentration of extractable cobalt. Sediment trace element concentrations appear to show less spatial variability within the Benton Lake complex than do water column concentrations. The reported nickel concentration exceeds mean values for soils and other surficial materials of the western U.S. by a factor of 4. Selenium, zinc and cobalt exceed the regional soil means by factors of 1.5 to 2.

Big Lake

Climatic setting. The MAPS database value for the net annual precipitation balance at Big Lake is -28 inches, placing the site among the most strongly evaporative of the sample wetlands. Mean monthly values for the Rapelje climatic station show a strong May-June peak in precipitation. The 3-year running average of total annual precipitation appears to show periodicity, with 6 to 9 years between peaks. Between 1975 and 1992, the 3-year average remained at or above the long-term mean during most year. Data for 1993 and 1994 were not retrieved for this station.

Geologic setting. According to published geologic mapping, the Big Lake basin is underlain by the Bearpaw Shale and lies along the eastern limb of the Lake Basin Anticline, a structural trap for hydrocarbons which supports oil and gas production in the area. Outcrops in the immediate vicinity of WET06 are a well-cemented, medium grained sandstone believed to be the Virgelle Sandstone. Surficial sediments at the sampling site are composed of moderately well-sorted sand, with finer grained material accumulated in surface depressions created during the alteration excavation and alteration of the site.

Hydrologic type. Big Lake proper is a structurally controlled depression lacking surface outflow, which receives runoff from the entire Cedar Creek basin. The WET06 site is a reconstructed basin at the inlet to Cedar Creek, intended to retain water from Cedar Creek during low-water periods. The WET06 site drains to the greater Big Lake basin, which has slightly lower elevation than the reconstructed wetland. Water also probably exits the sample site by infiltration into the sandy, recently disturbed substrate.

Basin characteristics. The large ephemerally flooded Big Lake basin has a low ratio of catchment to wetland area. The small wildlife enhancement site sampled at WET06, however, has a very high catchment to wetland ratio. The enhancement site is controlled by overflow to Big Lake proper at a maximum water depth of approximately 3 feet, or about 1.5 feet deeper than during the conditions observed in October 1994. Turnover of water in the sample site would be relatively rapid during Cedar Creek runoff events. Excavated depths vary within the enhancement site.

Water chemistry. At the time of sampling, the WET06 site contained "hypersaline" sodium sulfate water with relatively low bicarbonate and carbonate concentrations. Mineral equilibria indicate substantial oversaturation with carbonate species and near-equilibrium with gypsum (corroborated by the formation of authigenic gypsum(?) in samples collected in October 1994).

Phosphorous concentrations were moderate in comparison to hydrologically similar sites, while the ammonium and total organic carbon concentrations were toward the high end of the range for sites of this type.

Along with nearby Hailstone and Halfbreed Wildlife Refuges, Big Lake was one of a small handful of sample sites with detectable nickel found in the water column. Boron and zinc concentrations were relatively high in comparison to hydrologically similar sample sites. The arsenic concentration was below detection, unusual among the sampled sites.

Chemical history. No water quality analyses prior to the DHES sampling are known. During October of 1994 (six months after sample collection) field chemical parameters (pH and specific conductance) were spatially variable within the small constructed wetland area. Specific conductance measurements ranged from less than half that reported at the time of sampling, to 10% higher; the configuration of the constructed site may discourage rapid mixing of inflow from Cedar Creek. Water quality of Cedar Creek reflects evaporative concentration in upgradient water bodies (including Halfbreed Lake) and may be influenced by upgradient water management. No surface water quality data from Big Lake proper are known. In October 1994, the Big Lake basin retained surface water in a relatively small area near the center of the basin.

Sediments. In comparison to hydrologically similar sample sites, most trace elements were found in low to intermediate concentrations. The exceptions were selenium and vanadium; for these elements WET06 was at or near the top of the sampled range for similar sites. The selenium concentration was above the mean for soils and other surficial deposits of the western U.S.

Big Sandy DOT Mitigation Wetland

Climatic setting. The net annual precipitation balance for the Big Sandy site (from the MAPS database) is -26 inches, placing it toward the middle of the range for sample sites with which it is classified. Mean monthly precipitation shows a well-defined June maximum. The three-year moving average of annual total precipitation remained near or above the long-term average for most of the 1975-1990 period. The annual total in 1993 (the year prior to sampling) exceeded the long-term average by about 5 inches.

Geologic setting. The WET07 site is underlain by fine-grained paludal deposits capping the in-filled channel of the preglacial Missouri River. Geologic mapping shows stratified ice-contact deposits (kame terrace and esker) immediately upslope of the site, which may receive ground-water discharge from these sediments. 100 feet or more of alluvial fill underlies the paludal deposits in this area; this alluvium provides ground-water of variable water quality. The bedrock surface underlying the surficial deposits is comprised of the late Cretaceous Claggett Shale Judith River Formation.

Hydrologic type. Although located along a major intermittent(?) stream, the immediate sample site is an excavated basin reportedly lacking surface water outflow. Inflow is reported to be from ground-water sources.

Basin characteristics. The catchment to wetland area ratio for this site is very high if Big Sandy Creek contributes to the wetland's water balance. The reported lack of surface water inflow indicates the site may not be integrated into the Big Sandy drainage. Artificial excavation as a highway mitigation site is inferred to create disturbed and probably transient substrate conditions.

Water chemistry. Water of the Big Sandy wetland was of a relatively dilute (particularly for a Great Plains site), moderately alkaline sodium bicarbonate character. The WET07 analysis is at the lower end of the dissolved solids range reported for ground-water from surficial deposits in the area, and considerably more sodic in composition than similarly dilute ground-water samples. This distinction suggests shallow groundwater may not be the primary water source for the wetland. Mineral equilibria indicate oversaturation with carbonate species.

Nitrogen (nitrate plus ammonium), phosphorous (total and orthophosphorous) and total organic carbon concentrations are all toward the lower end for the class including WET07. Selenium was reported at the analytical detection limit; water column selenium was reported at only four other sample sites. Arsenic and boron concentrations were toward the low end of the range for site of this class. Most other trace elements were below detection limits.

Chemical history. No chemical data other than the DHES analysis are known for this site.

Sediments. Those extractable trace elements reported above detection limits were in the low to mid-range when compared with similar sampling sites. Only boron exceeded (marginally) the mean value for soils and other surficial materials of the western U.S.

Black Coulee National Wildlife Refuge

Climatic setting. The net annual precipitation balance for Black Coulee (estimated from the MAPS database) is -26 inches, placing the site near the center of the range shown for Great Plains sample sites. Mean monthly precipitation for the (inactive) Turner climatic station shows a strong June peak. Annual totals for the Harlem 4W station (the most relevant active station) are fragmentary since the early 1970s. From 1990 through 1992 (the three years prior to sampling) annual totals were below the long-term average.

Geologic setting. The Black Coulee site is underlain by till of uncertain character, possibly deposited as part of a marginal moraine complex ringing the Turner Plateau. Local alluvium within the Black Coulee drainage is probably composed of reworked till and sediments derived from the late Cretaceous Bearpaw Shale, which underlies surficial deposits in the area.

Hydrologic type. Black Coulee NWR is an artificial impoundment inferred (by low salinity) to have spilled water regularly during the recent past.

Basin characteristics. Black Coulee has a catchment to wetland area ratio in the mid-range for sample sites in it's class. A number of other, smaller reservoirs within the basin probably influence the runoff characteristics of the catchment, as may areas of internal drainage within the northern portion of the mapped catchment. Surficial and bedrock materials exposed in the basin are generally not amenable to much ground-water flow.

Water chemistry. At the time of sampling, water at Black Coulee NWR was of a relatively dilute, moderately alkaline mixed-cation/bicarbonate character with proportionately low calcium concentration. Mineral equilibria indicate near-equilibrium with respect to calcite and aragonite. Nutrient concentrations were low to moderate in comparison to sample sites of this class. Arsenic and boron concentrations were low in comparison to similar sample sites, and with the exception of lead, other trace element concentrations were below detection limits. Lead was reported at the detection limit, one of a handful of sites with reportable concentrations.

Chemical history. No other water chemistry data from Black Coulee are known. Previous sediment sampling was conducted by the U.S. Fish and Wildlife Service (see below).

Sediments. Black Coulee was at or near the high end of the range for it's class in a number of trace elements, including arsenic, copper, chromium, and nickel. Western U.S. mean values for soils and other surficial deposits were exceeded for arsenic (by a factor of about 2), boron (2), copper (1.5), and cobalt (1.5). Reported values for nickel and zinc barely exceeded the regional soils

means.

A sediment sample collected in 1987 by the U.S. Fish and Wildlife Service shows a similar pattern of trace element elevation, with reported concentrations for individual elements differing from the DHES results by as much as a factor of 2.

Blackfoot Meadows

Climatic setting. The net annual precipitation balance for Blackfoot Meadows (from the MAPS database) is -2 inches, placing the site near the humid end of the range shown by the sample sites. Mean monthly precipitation for the Basin climatic station (across a major drainage divide from the site) shows a bimodal distribution, with a primary June maximum and a secondary January peak. The three-year running average of annual precipitation for the Boulder station (also at some distance from the site) shows values below the long-term mean for much of the 1980s and near or above the long-term average for 1990-93, with precipitation in 1993 (the year of sampling) almost 6 inches above average. [Water supply to Blackfoot Meadows is probably supported mainly by winter snowpack, however, which is not reflected in data from these low-elevation stations.]

Geologic setting. Surficial deposits in the upper Little Blackfoot basin have been interpreted as glacial in origin, derived from local igneous lithologies. Blackfoot Meadows itself is underlain by alluvial and paludal deposits of unknown depth. Bedrock in the contributing drainage basin is composed of felsic to intermediate volcanic and intrusive lithologies of late Cretaceous and early Tertiary age. Outcrops in the immediate area of Blackfoot Meadows are Tertiary rhyolitic tuffs.

Hydrologic type. Blackfoot Meadows is an area of low hydraulic and topographic gradient along the channel of the Little Blackfoot River. Inflow is from the Little Blackfoot and tributary streams, and outflow is via the Little Blackfoot River. The valley profile and cross-section suggest alluvial deposition in an over-deepened or geologically impounded valley segment. Beaver activity now influences throughflow and stream gradients.

Basin characteristics. The catchment contributing to this wetland has high relief and an intermediate catchment to wetland area ratio for Rocky Mountain sites. The distribution of different hydrologic regimes within the wetland is probably relatively transient due to the activities of beavers.

Water chemistry. Water chemistry at this site is mildly acidic and very dilute. Mineral equilibria indicate substantial undersaturation with respect to the phases evaluated, but censored data and poor ion balance limit the usefulness of these calculations. Nitrate and ammonium concentrations were below detection limits; the orthophosphorous concentration was mid-range among sites of this class, and the total organic carbon concentration was toward the lower end of the class range.

Arsenic was reported at twice the detection limit (mid-range for sites of this class), and iron was reported at a concentration mid-range for the sample set. Most other trace element concentrations were below detection limits.

Chemical history. No other chemical data for Blackfoot Meadows are known. Little spatial variability should be expected; somewhat higher mineralization would probably be seen at other times of year when base flow conditions in the Little Blackfoot River are approached.

Sediments. Extractable concentrations of most trace elements were below detection limits. The arsenic concentration was in the upper half among sites of this type; zinc, copper, manganese and iron were toward the lower end of their respective ranges. None significantly exceeded regional western U.S. means for soils.

Blackfoot Waterfowl Production Area

Climatic setting. The net annual precipitation balance for the Blackfoot WPA (from the MAPS database) is -12 inches, putting the site toward the moist end the range shown by this site class. Mean monthly precipitation for the Ovando 9SSE climatic station shows a bimodal distribution, with a primary June maximum and a secondary January peak. The 3-year running average of total annual precipitation for this station has remained below (often well below) the long-term average for most of the period since the mid-1970s. Total precipitation in 1993 (the year of sampling) approximated the long-term average.

Geologic setting. The Blackfoot WPA site is underlain by late Pleistocene glacial outwash(?) elevated a few feet above, and graded to, the floodplain of the nearby Blackfoot River. The source area for the glacial sediments is the basin of the North Fork of the Blackfoot River.

Bedrock in the small contributing catchment includes formations of the Ravalli Group of the Proterozoic Belt series and Cretaceous and Tertiary igneous rocks. Mineralization associated with these igneous rocks occurs nearby. Formations exposed in the North Fork basin include Proterozoic and Cambrian limestone and dolomite.

Hydrologic type. The Blackfoot WPA site is a shallow glacial basin (kettle?) augmented by dikes and equipped with an outlet control structure. Prior to the WPA enhancement project, the natural wetland had been ditched and largely drained. Inflow to the wetland is via culverts beneath Highway 200, which isolates the site from most of its natural surface catchment and from reported spring sources on the upgradient side of the road.

Basin characteristics. The broad, shallow(?) natural basin of this wetland has been altered by both diking and excavation to provide deeper-water and more perennial conditions. The natural catchment is relatively small relative to the wetland area, but ground-water discharge apparently supporting the wetland would not necessarily be expected to follow the low northern drainage divide. Surface drainage from upgradient areas is altered by the existence of Highway 200.

Water chemistry. Water collected from the Blackfoot WPA was relatively dilute, mildly alkaline and dominated by bicarbonate, calcium and magnesium ions. Mineral equilibria indicate slight undersaturation with carbonate phases. Nitrate, ammonia and orthophosphorous concentrations were low; the total organic carbon concentration was mid-range for sample sites similarly classified.

Arsenic and copper were found at concentrations near the lower end of the ranges shown by sites of this class. Most other trace element concentrations were below detection limits.

Chemical history. No other chemical data are known for this site. Unmanipulated closed-basin lakes and wetlands in the vicinity often develop more alkaline and somewhat more saline water chemistry characteristics than shown by WET10, possibly giving an indication of this site's general character prior to alteration.

Sediments. Extractable arsenic, copper and zinc were reported at mid-range concentrations for sample sites similarly classified. Only copper exceeded the western U.S. mean for soils and other surficial materials (by a factor of about 1.25).

Brush Lake

Climatic setting. The net annual precipitation balance for Brush Lake derived from the MAPS database is -23 inches, toward the less evaporative end for sites in this class. Based on analyses of evaporation pan data, this is a considerable underestimate Brush Lake's water deficit, and points out the need to view the MAPS estimates only as relative indicators of net site precipitation. Mean monthly precipitation for the Medicine Lake climatic station shows a pronounced June maximum. Annual totals for this station show apparent periodicity with a 5 to 7 year cycle. Throughout the 1980s, the 3-year running average remained below (often well below) the long-term average, recovering in the early 1990s. In 1993 (the year before sampling) precipitation exceeded the long-term average by more than 1 inch.

Geologic setting. Brush Lake occupies an ice-block depression (kettle) in the sequence of late Pleistocene outwash sand and gravel forming the Clear Lake aquifer. Surficial sediments within the lake basin are dominated by authigenic carbonate minerals precipitated from in-flowing ground water. Glacial sediments are underlain at depth by the early Tertiary Fort Union Formation.

Hydrologic type. Brush Lake is a glacial depression lacking surface water outflow or significant surface water inflow. Flow-through ground water dynamics in an evaporative setting maintain water chemistry within a limited range. Brush Lake is believed to have been internally drained (with respect to surface water) and perennial throughout postglacial time. In-flowing ground-water is supersaturated with carbonate phases upon loss of CO₂ to the atmosphere, resulting in the deposition of extensive tufa and marl deposits.

Basin characteristics. Brush Lake has a minimal surface catchment, exhibiting the lowest surface catchment to wetland area ratio of any sample site. The lake basin is relatively steep-sided and deep; maximum lake depth is approximately 60 feet. Regional ground-water flow through the Clear Lake aquifer and its tributary Grenora channel flows through Brush Lake, controlled by local stratigraphy, aquifer head distribution and evaporative withdrawals.

Water chemistry. Brush Lake contains alkaline, "oligosaline" sodium-sulfate/carbonate water almost completely depleted in calcium. Major-ion aqueous chemistry is controlled by the precipitation of calcium and magnesium carbonates. At the time of sampling, nitrogen (nitrate and ammonia) concentrations were below detection limits, and phosphorous concentrations (total and orthophosphorous) were near the lower end of the range shown by sample sites in this class.

In arsenic and boron concentrations, Brush Lake was among the upper 25% among its classification. The reported iron concentration was

low with respect to all sample sites, and most other trace elements analyzed were below detection limits.

Chemical history. Brush Lake has a record of field and quantitative water chemistry analyses related to investigations of the Clear Lake aquifer system and to the dynamics of ground-water supported evaporative lakes. Specific conductance measurements dating back to 1984 show an overall range from 5360 to 6140 microsiemens/cm with a relatively well-mixed, near-homogeneous water column during summertime conditions. Monthly time-series water quality sampling conducted in 1984 and 1985 has not yet been analyzed. Brush Lake is believed to have been perennial throughout it's Holocene history.

Sediments. Sedimentation in Brush Lake is dominated by authigenic tufa and marl formation, in part mediated by biological activity. Detrital sediments are a relatively minor component of the system. However, the WET11 sampling site is along a relatively exposed, winnowed shoreline and allogenic detrital material may be over-represented in this sample relative to other littoral areas. Extractable calcium and magnesium concentrations in the percent range would be expected from different shoreline settings.

Extractable arsenic was reported at the second-highest concentration for this sample site classification. Boron, iron, manganese and zinc were reported at concentrations near the lower end of the ranges shown for this site classification. Most other trace elements were below detection limits. Arsenic exceeded mean soil concentrations for the western U.S. by a factor of about 2.

Burns Creek

Climatic setting. The net annual precipitation balance for the Burns Creek site (estimated from the MAPS database) is -26 inches, toward the less strongly evaporative end of the range shown by sites in this classification. Mean monthly precipitation for the Savage climatic station shows a pronounced June maximum. For most of the 1980s, the 3-year running average of annual precipitation remained below the long-term average for the Savage station. From 1990 through 1993, the 3-year average was near or above the long-term average. In 1993, the year prior to sampling, precipitation exceeded the long-term average by about 2 inches.

Geologic setting. The Burns Creek drainage is incised into early Tertiary sandstone, shale and clinker of the Fort Union Formation, overlain in places by the Miocene Flaxville Formation or equivalents. Sediments deposited in the Burns Creek valley may reflect late Pleistocene glacial drainage across the Burns Creek/Redwater River divide; alluvium associated with the North Fork of Burns Creek appears to be unusually thick and permeable for a prairie stream, and probably includes glacially transported calcareous material. Ground water stored in this alluvium supports a wetland complex and is drained by lower Burns Creek.

Permeable surficial or near-surface material (Flaxville Formation gravels and/or clinker) caps the upland surface in many areas; where incised by Burns Creek, stratigraphically controlled ground-water discharge occurs. Contact springs of this type help support flows in Burns Creek and the WET12 wetland.

Hydrologic type. The Burns Creek wetland occupies an unglaciated setting influenced by periods of fluvial erosion and deposition by glacial drainage. The site has at least intermittent surface water inflow and outflow and may also be supported by local ground-water discharge. The contributing surface drainage basin probably receives contact-controlled ground water discharge in its headwaters.

Basin Characteristics. The WET12 site is near the confluence of Burns Creek and the North Fork of Burns Creek. The (estimated) ratio of catchment to wetland area is toward the high end of the range shown by sites classified with WET12. The North Fork of Burns Creek is known locally to flow only during runoff, probably due to the relative permeability and depth of the North Fork alluvium. Burns Creek (mainstem) is also underlain by permeable gravels which support moderately yields from a nearby irrigation well.

The Burns Creek road probably influences runoff and ground-water flow paths in the vicinity of the WET12 site.

Water chemistry. At the time of sampling, WET12 water was of a moderately alkaline "oligosaline" character. Divalent cations

(calcium and magnesium) and sodium were present in similar proportions. Mineral equilibria indicate oversaturation with carbonate phases. Nitrate and ammonia concentrations were below detection limits, and phosphorous concentrations (total and orthophosphorous) were near the lower end of the ranges shown for all sample sites.

Arsenic, boron, copper and iron concentrations were low to moderate in comparison to similarly classified sites. Zinc and lead were reported at concentrations near the high end of the range shown for the classification. Most other trace element concentrations were below detection limits.

Chemical history. No other water quality data from this site are known. The site is probably leant hydrologic stability by groundwater storage in the Burns Creek alluvium and (possibly) in upland gravels and clinker; water quality variability may be less than for many of the plains sampling sites.

Sediments. Extractable copper, boron, arsenic, vanadium, nickel and zinc were all reported at concentrations near the lower end of their respective ranges for sites classified with Burns Creek. The reported boron concentration exceeded the mean for western U.S. soils by a factor of two; concentrations of other elements were below regional mean soil values.

Colter Campground

Climatic setting. The net annual precipitation balance estimated from the MAPS database for the Colter Campground is 44 inches. Because both precipitation and evaporation estimates are subject to large uncertainties in this high-relief setting, this value is not thought to have significance beyond indicating the precipitation-surplus character of the site. Mean monthly precipitation for the Cooke City climatic station shows relatively evenly distributed precipitation throughout the year. Annual totals for Cooke City show below-average values throughout the late 1980s and early 1990s. The total precipitation in 1993 (the year prior to sampling) was near the average for the period of record.

Geologic setting. Glacial deposits of unknown but probably coarse-grained character underlie the site and are inferred to impound the wetland basin. Local lithologies which are inferred to have contributed to glacial sediments include Archaean gneiss and (probably) mafic to intermediate volcanic and intrusive rocks and (possibly) Paleozoic sedimentary formations. At the site of the sample wetland, glacial deposits overlie metamorphic rocks of Archaean age.

Hydrologic type. The Colter Campground wetland is a high-elevation glacial depression lacking mapped surface water inflow or surface water outflow. Because the site is in an area of precipitation surplus yet lacks surface outflow, it is inferred that ground-water outflow is important to the wetland's water balance.

Basin characteristics. The surface catchment to wetland area ratio derived from topographic mapping of this site is relatively high. Map information may underestimate the area of the wetland, however. Inflow to the wetland is inferred to be from runoff and local ground-water flow within the small catchment, driven by relatively high precipitation rates.

Water chemistry. The Colter Campground wetland contains dilute, near-neutral calcium/bicarbonate water. Mineral equilibria indicate substantial undersaturation with respect to carbonate phases. Nitrate and ammonia concentrations were below detection limits at the time of sampling. Orthophosphorous and total phosphorous concentrations were low in comparison to sample sites of all classes. The total organic carbon concentration reported is mid-range with respect to the range shown by sample sites of this class.

Among sample sites in the same class, WET13 ranks near the middle in iron concentration. Most trace elements were reported to be below detection limits.

Chemical history. No other chemical data for this site are known. By inference, water chemistry in this site probably varies over a narrow and dilute range.

Sediments. The reported zinc, nickel, lead and selenium concentrations ranked this site toward the upper end of the ranges shown by this site classification. Reported arsenic, boron and copper concentrations ranked low to intermediate within the site classification. The reported selenium concentration exceeded the mean soil concentration for the western U.S. by a factor of 1.7; the zinc concentration exceeded the western U.S. mean by a factor of less than 1.2.

Comertown Preserve

Climatic setting. The net annual precipitation balance for the Comertown Preserve site (from the MAPS database) is -20 inches, ranking the site toward the less evaporative end of the range shown for this classification. Mean monthly precipitation for the Westby climatic station shows a pronounced June maximum. Annual total precipitation records are incomplete through the 1980s for the Westby station. For the years available during the 1980s, 3-year averages of the annual total were well below the average for the period of record. Regional trends during the missing years (1985-87) indicate precipitation was above average in 1986 and below average in 1985 and 1987. The 3-year average was near or above the long term average in the early 1990s.

Geologic setting. The Comertown Preserve is underlain by calcareous till of late Pleistocene age. Geologic mapping shows isolated deposits of stratified glacial drift in the general vicinity of the preserve, but the site lies well to the west of the known distribution of regional gravel aquifers. The till and other surficial deposits are underlain by the early Tertiary Fort Union Formation.

Hydrologic type. The Comertown Preserve site is a glacial depression (kettle) lacking surface outflow under most(?) conditions. During moist periods, the pond may be joined with adjacent intermittently flooded depressions. The comparatively dilute water chemistry observed at the site suggests ground-water outflow may be significant to the site's water and solute budgets.

Basin characteristics. Based on available topographic mapping, the Comertown Preserve appears to have only a minimal surface catchment beyond the wetland itself. However, the fine scale knob-and-kettle topography characterizing the area makes it difficult to be sure of the true position of local drainage divides. Overflow from adjacent, apparently separate basins, may occur.

Water chemistry. At the time of sampling, Comertown Preserve held alkaline, "oligosaline" water lacking dominant ionic composition. Equilibrium calculations indicate substantial oversaturation with carbonate phases. Ammonium, orthophosphorous and total organic carbon concentrations ranked this site toward the upper end of its classification. Most trace elements were below detection limits in the water column. Reported arsenic and boron concentrations ranked the site toward the lower end of its class, while zinc and copper concentrations ranked in the upper half within the site's classification.

Chemical history. No other chemical data for this site are known.

Sediments. Arsenic, boron, copper and zinc concentrations rank this site toward the middle or lower end of its classification. Chromium, nickel, selenium, and vanadium concentrations ranked

toward the higher end of the classification. Boron exceeded mean soil concentrations for the western U.S. by a factor of 2 and selenium by a factor of 1.7. Other trace element concentrations were below the regional mean soil values.

Condon Creek Proposed RNA Pond #1

Climatic setting. The net annual precipitation balance for the Condon Creek sites (from the MAPS database) is -8 inches, ranking these sites toward the less evaporative end of the range shown by sites of this classification. Mean monthly precipitation for the Lindbergh Lake climatic station shows a relatively even distribution with a January maximum. Annual precipitation totals show the 3-year running average below the average for the period of record throughout the 1980s. The running average recovered to approximate the long-term average from 1990 to 1992. Data for 1993 were not recovered for this station.

Geologic setting. The Condon Creek ponds are small glacial(?) depressions in till of late Pleistocene age. The texture and hydraulic characteristics of the till have not been described for this area. Other glacial, fluvial and colluvial sediments may be interbedded with till in the area. Any surficial sediments likely include calcareous material derived from source areas underlain by limestone and dolomite.

The ponds occupy positions near the toe of the fault-bounded Swan Range, which is underlain by argillitic and calcareous formations of the Proterozoic Belt series.

Hydrologic setting. The Condon Creek sites are glacial basins lacking surface water outflow or discrete surface water inflow. Dilute water chemistry suggests that water is supplied mainly by precipitation and very local runoff.

Basin characteristics. The Condon Creek ponds have very small surface catchments and low catchment to wetland area ratios. Depths of the ponds are unmeasured but probably shallow. Topographic position suggests the possibility of ground-water discharge to the ponds, but their dilute water chemistry is probably inconsistent with volumetrically important ground-water inflow.

Water chemistry. Water chemistry in WET15 is very dilute, mildly acidic and dominated by calcium and bicarbonate ions. Mineral equilibria indicate substantial undersaturation with carbonate species. Ammonium concentrations were high in this site, ranking near the top for sites of this classification. Orthophosphorous and total phosphorous concentrations ranked in the mid-range for sample sites of this class. The total organic carbon concentration was the highest for this class and among the highest for the entire sample set.

Arsenic and zinc were reported at their respective detection limits; the iron concentration ranked in the mid-range for sites in this class. Most other trace elements were below reporting limits.

Chemical history. No other chemical data are known for this site.

Sediments. Arsenic, copper, selenium, vanadium and zinc were reported in concentrations above detection limits. Copper and selenium concentrations ranked toward the top for sample sites in this class, while arsenic, vanadium and zinc concentrations ranked near mid-range for their classification. Selenium exceeded the mean soil concentration for the western U.S. by a factor of two, copper by a factor of 1.5 and zinc by a negligible amount.

Condon Creek Proposed RNA Pond #2

Climatic setting. The net annual precipitation balance for the Condon Creek sites (from the MAPS database) is -8 inches, ranking these sites toward the less evaporative end of the range shown by sites of this classification. Mean monthly precipitation for the Lindbergh Lake climatic station shows a relatively even distribution with a January maximum. Annual precipitation totals show the 3-year running average below the average for the period of record throughout the 1980s. The running average recovered to approximate the long-term average from 1990 to 1992. Data for 1993 were not recovered for this station.

Geologic setting. The Condon Creek ponds are small glacial(?) depressions in till of late Pleistocene age. The texture and hydraulic characteristics of the till have not been described for this area. Other glacial, fluvial and colluvial sediments may be interbedded with till in the area. Any surficial sediments likely include calcareous material derived from source areas underlain by limestone and dolomite.

The ponds occupy positions near the toe of the fault-bounded Swan Range, which is underlain by argillitic and calcareous formations of the Proterozoic Belt series.

Hydrologic setting. The Condon Creek sites are glacial basins lacking surface water outflow or discrete surface water inflow. Dilute water chemistry suggests that water is supplied mainly by precipitation and very local runoff.

Basin characteristics. The Condon Creek ponds have very small surface catchments and low catchment to wetland area ratios. Depths of the ponds are unmeasured but probably shallow. Topographic position suggests the possibility of ground-water discharge to the ponds, but their dilute water chemistry is probably inconsistent with volumetrically important ground-water inflow.

Water chemistry. At the time of sampling, water at the WET16 site was very dilute, mildly acidic and calcium/bicarbonate in character. Mineral equilibria indicate substantial undersaturation with respect to carbonate phases. Nitrate and ammonium concentrations were lower than nearby WET15; nitrate was below detection limits and in ammonium concentration the site ranked toward the middle of sites in its classification. The orthophosphorous concentration reported was considerably higher than for WET15 (ranking near the top for this site type), while the total phosphorous concentration was considerably lower than at WET15. The total organic carbon concentration was considerably lower than for WET15 but still ranked near the top for sites of its class.

Arsenic was reported at the detection limit; copper and iron

concentrations ranked mid-range for sample sites in this class. Other trace elements were below detection limits.

Chemical history. No other chemical data are known for this site.

Sediments. Extractable trace element concentrations showed a similar pattern to that for WET15. Copper and selenium concentrations ranked toward the high end for the site classification; arsenic and zinc concentrations ranked in the mid-range. Selenium and copper concentrations exceeded mean soil concentrations for the western U.S. by factors of 2, while arsenic and zinc concentrations were less than the regional soil means.

Creedman Coulee National Wildlife Refuge

Climatic setting. The net annual precipitation balance for the Creedman Coulee site (from the MAPS database) is -25 inches, mid-range in comparison to sites of it's classification. Mean monthly precipitation for the Fort Assiniboine climatic station shows a pronounced June maximum. The 3-year moving average of annual total precipitation shows an apparent periodicity with maxima on 4 to 6 year intervals. The moving average remained near or above the long-term mean from 1974 through 1993; in 1993 (the year prior to sampling) total precipitation exceeded the long-term mean by about 7 inches.

Geologic setting. Creedman Coulee is underlain by late Pleistocene till of undescribed character. The till is inferred to be calcareous, shaley and of low permeability. The valley floor of Creedman Coulee is underlain by modern alluvium of unknown character and possibly by glaciofluvial sediments.

At the wetland site and throughout most of the Creedman Coulee basin, glacial sediments are underlain by the late Cretaceous Bearpaw Shale; in some of the upper basin the Judith River Formation underlies the surficial deposits.

Hydrologic type. WET17 is located on Creedman Reservoir, an artificial impoundment of Creedman Coulee. The reservoir has an outflow structure and is inferred to discharge water fairly regularly due to the relatively dilute water chemistry shown.

Basin characteristics. No information on the maximum depth or volume of Creedman Reservoir is available. The catchment area to wetland area ratio ranks mid-range for sample sites in this classification. Numerous small stock-watering reservoirs scattered throughout the catchment probably influence the timing and quantity of runoff received by Creedman Reservoir.

Water chemistry. At the time of sampling, Creedman Reservoir's was relatively dilute and moderately alkaline, with similar equivalent proportions of divalent (calcium and magnesium) and monovalent (sodium and potassium) cations and bicarbonate-dominated anion chemistry. Mineral equilibria indicate moderate oversaturation with carbonate phases. Nitrogen concentrations (nitrate plus ammonium) were low in comparison to the range shown by this site classification; phosphorous concentrations (total and orthophosphorous) were mid-range for sites of this classification, as was the total organic carbon concentration.

The boron concentration reported for WET17 was among the highest in the data set, and the highest for any site with surface water outflow. The arsenic concentration ranked near the middle of the range for this class, and the chromium concentration was comparatively high. The iron concentration ranked comparatively low, and the other trace elements were below detection limits.

Chemical history. No other water chemistry data are known for this site. It is inferred that surface outflow maintains salinity within a moderate range.

Sediments. Arsenic, boron, vanadium and zinc concentrations were all of intermediate rank in comparison to sites within this classification. Arsenic and boron concentrations were slightly above mean values for soils and other surficial sediments of the western U.S. Vanadium and zinc concentrations were below mean values for western U.S. soils. Other trace element occurrences were below reporting limits.

Dudley Slough Preserve

Climatic setting. The net annual precipitation balance for the Dudley Slough (from the MAPS database) is -12 inches, ranking the site as one of the more strongly evaporative of Rocky Mountain sites. Mean monthly precipitation for the Fortine climatic station shows a relatively even seasonal distribution with a June maximum. Annual totals show the 3-year running mean remaining below the long term mean for most of the period from 1970 to 1987. Total precipitation in 1993 (the year prior to sampling) was about 5 inches above the long-term mean.

Geologic setting. Dudley Slough lies in glaciated terrain and is inferred to be underlain by till and possibly other late Pleistocene glacial sediments. Based on available source lithologies, glacial deposits can be inferred to be calcareous. Bedrock formations underlying the site are of the Proterozoic Belt series, including the calcareous Siyeh Formation. Glacial processes have given the general area a prominent northwest trending drumlinoid lineation.

Hydrologic type. Dudley Slough is a natural glacial depression with channelized surface water inflow and outflow.

Basin Characteristics. The catchment area to wetland surface area ratio for Dudley Slough ranks mid-range among sample sites of similar type. The maximum reported depth of the pond is 6 meters.

Water chemistry. Dudley Slough contains relatively dilute, moderately alkaline calcium-magnesium/bicarbonate water. Mineral saturation indices indicate moderate oversaturation with carbonate species; authigenic carbonate deposition appears to be verified by the exceptionally high extractable calcium concentration reported for Dudley Slough sediments. Nitrate, ammonium and orthophosphorous concentrations were below detection limits. The total phosphorous concentration ranked in the mid-range for sample sites of this type, and the total organic carbon concentration was toward the lower end of the range for all sample sites. Copper was reported at the detection limit, and other trace elements were below detection limits.

Chemical history. A single previous partial chemical analysis is known for a sample collected in July of 1988. The reported specific conductance at that time was 75% of the August 1994 value. The concentrations of major cations and of alkalinity were very close in the two samples (raising some doubt about the 1988 specific conductance measurement.) Trace element concentrations were not analyzed for the 1988 sample. Generally, variability is not expected to be very great at this site.

Sediments. A very high extractable calcium concentration probably indicates a high fraction of authigenic calcium carbonate in Dudley Slough's sediments. Arsenic, aluminum and iron concentrations were

all ranked at or near the bottom of their ranges for this site type and near the bottom for the entire sample set. The manganese concentration ranked in the mid-range among comparable sites. Other trace element concentrations were below detection limits. All were below mean soil concentrations for the western United States.

Evans Lake

Climatic setting. The net annual precipitation balance for Evans Lake (from the MAPS database) is -16 inches, placing the site toward the more evaporative end of the range for its hydrologic classification. Monthly average precipitation for the Ovando 9SSE station shows a bimodal distribution, with a primary May-June peak and a secondary winter peak. Since the mid-1970's, the 3-year running average of annual total precipitation has been below (often well below) the average for the period of record. Total precipitation in 1993 (the year of DHES sampling) was very near the long-term average.

Geologic setting. Evans Lake is a steep-sided glacial kettle developed in till deposited by ice advancing into the Ovando Valley from the North Fork of the Blackfoot River. Surficial sediments in the Evans Lake basin are notably cobbly in texture, and may include glaciofluvial deposits as well as till. Littoral sediments typically feature gravel and cobbles in a matrix of marly mud.

Bedrock geologic units underlying Evans Lake are not exposed in the immediate area; generally the Ovando Valley is underlain by a sequence of Tertiary valley-fill sediments overlying Proterozoic metasediments of the Belt series. Belt sediments exposed in the North Fork drainage (inferred to contribute to the North Fork) include large outcrop areas of the Helena Formation and other calcareous and dolomitic units.

Hydrologic type. Evans Lake is a glacial depression lacking surface drainage at current water levels. Strandlines represented by tree kills indicate historic water levels within the past few decades which may have allowed surface discharge. Ground water is inferred to be an important contributor to Evans Lake; based on the relatively high salinity observed in the lake, ground-water outflow is probably restricted.

Basin characteristics. Evans Lake has a small surface catchment with respect to lake area and volume. The basin is steep-sided and relatively deep, with a maximum measured depth of 25.5 feet in September 1994. High-water drainage, if any, would occur through a gap along the northeast quadrant of the lake.

Water chemistry. Evans Lake contains "mesosaline" sodium sulfate water nearly depleted in calcium. Very low calcium concentrations are probably maintained by solubility controls; equilibrium calculations indicate supersaturation with carbonate species.

In comparison to hydrologically similar sites, Evans Lake (at the time of sampling) was relatively low in orthophosphorous concentration. Nitrate and ammonium concentrations were mid-range among hydrologically similar sites. (Ammonium concentrations measured during winter conditions were considerably higher - see below.) The total organic carbon concentration was near the middle of the range for hydrologically similar sites.

Evans Lake has one of the highest water column arsenic concentrations of the sample sites. Most other trace elements were below detection limits.

Chemical history. A single previous chemical analysis is known from Evans Lake. This sample, collected in September of 1972, showed a total dissolved solids concentration of 6310 mg/l (compared to 9743 mg/l in 1993). The overall sodium - sulfate character of the water was similar the 1993 analysis; the calcium concentration was slightly higher but still very low.

Specific conductance measurements in September of 1994 were approximately 15% higher than in August of 1993. Shoreline evidence of substantially higher water levels in the historic(?) past indicate significantly higher lake volume and more dilute water chemistry.

Winter measurements through a continuous ice cover showed near-complete oxygen depletion of the water column above the lake's deepest point. Winter sampling showed ammonium concentrations 7 to 8 times the concentration measured at WET19 in August of 1993.

Sediments. Evans Lake sediments contain arsenic and iron concentrations near mid-range for hydrologically similar sites and zinc concentration near the lower end for sample sites of this class. Other trace element concentrations were below detection limits. High calcium concentrations probably reflect the precipitation of authigenic carbonate minerals.

Fox Lake

Climatic setting. The net annual precipitation balance for Fox Lake (from the MAPS database) is -25 inches, placing the site near the less intensely evaporative end of the range shown by this classification. Mean monthly precipitation for the Savage climatic station shows a pronounced June peak. The 3-year running average of total annual precipitation for this station remained near or below the long-term average through most of the 1980s; from 1991 to 1993 the 3-year average exceeded the long-term average. Total precipitation in 1993 (the year prior to sampling) exceeded the long-term average by about two inches.

Geologic setting. Fox Creek and Fox Lake lie along a mid(?) - Pleistocene glacial drainage way continuous across the modern drainage divides between Redwater Creek, Fox Creek and the North Fork of Burns Creek. Glacial drainage through this system may have deposited glaciofluvial sediment in places along Fox Creek; alluvium of unspecified character is reported to underlie Fox Creek to a depth up to 30 feet. Fox Lake existed as a natural feature prior to dam construction; Holocene-aged lacustrine sediments probably underlie the lake basin.

Surficial deposits are underlain by the Tullock Member of the Fort Union Formation.

Hydrologic type. Fox Lake is an artificial impoundment with a managed(?) outlet structure. Although beyond the maximum extent of Pleistocene glaciation, Fox Creek appears to owe its character to Pleistocene drainage of glacial meltwater from an ice front to the north.

Prior to damming, Fox Lake was described as perennial but seasonally highly variable in extent. Outflow from the lake may have been seasonal, with periods of basin closure to surface water.

Basin characteristics. Fox Lake is toward the large end of the size distribution for the DEQ wetland characterization sites, with a contributing basin to wetland area ratio near the median. Low-gradient streams occupying the Redwater River-Fox Creek glacial drainageway provide inflow and outflow. The depth of Fox Lake is unknown but believed to be shallow throughout. The lake basin is divided lengthwise by a railroad berm separating the largest inlet stream (entering north of the railroad) from the outlet stream exiting from the southeastern quadrant. Restricted water circulation across this barrier may lead to exaggerated chemical gradients within the lake basin.

Water chemistry. At the time of sampling, Fox Lake contained alkaline, "oligosaline" sodium sulfate water; mineral equilibria indicate considerable oversaturation with carbonate phases. Nitrogen concentrations (nitrate and ammonium) were below detection limits and in the lower class rankings, respectively.

Concentrations of other nutrients ranked generally mid-range for sites in this classification.

Arsenic, boron, chromium, and copper concentrations ranked mid-range for sites in this classification. Reported lead and iron concentrations ranked toward the upper end of their respective ranges.

Chemical history. No previous water quality data are known for Fox Lake. The reported character of the lake prior to impoundment (perennial but highly variable in extent) suggests that salinity and other chemical characteristics were probably more variable in the past than now.

Sediments. The concentration of arsenic reported for WET20 ranked near the upper end of the range shown by sample sites in this classification. Concentrations of boron, copper, chromium, nickel, vanadium and zinc ranked mid-range in their respective ranges for sites classified with WET20. Fox Lake was among a small handful of sites not known to be impacted by mining or mineralization where mercury was reported from sediment (at the detection limit).

The boron value exceeded the mean soil concentration for the western U.S. by a factor of 1.6, and nickel and zinc concentrations exceeded regional mean soil values by small factors. Other trace element concentrations were reported below the regional mean soil concentrations.

Freezeout Lake

Climatic setting. The net annual precipitation balance for Freezeout Lake is -27 inches, toward the more strongly evaporative end of the range shown by sites in this classification. Monthly average precipitation for the Choteau climatic station shows a pronounced June maximum. Annual totals for this station show the 3-year running average below (often well below) the long-term average throughout most of period from 1970 to 1990. The total precipitation in 1992 (the year prior to sample collection) was almost 4 inches below the long-term average, while the 1993 total exceeded the long-term average by over 4 inches.

Geologic setting. The Freezeout Lake basin is underlain by a sequence of glaciolacustrine silt and clay deposited toward the western limit of the extensive Glacial Lake Great Falls, and by the Late Cretaceous Marias River Shale, Telegraph Creek Formation and Two Medicine Formation. Permeable terrace gravel deposits underlie some upland areas.

Hydrologic type. Freezeout Lake and the surrounding ponds make up a complex of diked and managed water bodies receiving irrigation return flows from the Greenfields Division of the Sun River Irrigation Project. Peripheral ponds drain to Freezeout Lake proper through regulation structures. Managed outflow occurs via Priest Butte Lakes to the Teton River at times of high streamflow. Water levels are manipulated to meet water storage objectives in the lake system and water quality objectives in both the lake system and the Teton River.

Basin characteristics. Freezeout Lake occupies the lower elevations of a broad, low-gradient depression altered by diking, ditching and transportation corridors. The catchment to wetland area ratio is relatively low, but a large fraction of the inflows to the lake system are irrigation return flows imported from outside the natural drainage basin. Water depths are shallow (maximum depth estimated to be 10-12 feet) and portions of the lake system are surrounded by low-gradient salinated flats.

Water chemistry. At the time of sampling, water at the WET21 site was mildly alkaline, "oligosaline" and sodium sulfate in character. Equilibrium calculations indicate near-saturation with calcium carbonate species and substantial oversaturation with respect to dolomite. With respect to sample sites in the same classification, WET21 ranked mid-range in ammonium and total organic carbon concentrations, relatively low in orthophosphorous concentration and relatively high in total phosphorous.

Within its class, the arsenic and copper concentrations ranked mid-range and the boron concentration was near the high end of the range.

Chemical history. Several samples were collected by the U.S.

Geological Survey near WET21 in 1991 and 1992, and sampling elsewhere in Freezeout Lake occurred in 1987; DHES collected time-series sampling of the Freezeout-Priest Butte Lakes-Teton River system in 1980-82. In comparison to the WET21 sample, specific conductance near the WET21 site was up to 1.5 times higher in 1992. Within the short period of record, ammonium concentrations varied by a factor of 5 and orthophosphate concentration by a factor of 4.

Specific conductance measurements collected by DHES from 1980 to 1982 at the outflow from Freezeout Lake show a range from 3000 to 8500 microsiemens/cm. Six drains conveying irrigation return flows into Freezeout Lake ranged in average specific conductance from 832 to 4900 microsiemens/cm. The evaporative setting, shallow water depths and variability in inflow water quality imply significant spatial variability in water quality within Freezeout Lake. Trace element concentrations (notably selenium) are elevated in certain inflows remote from the WET21 site, and may be largely removed from the water column by geochemical process in the vicinity of inflow.

Sediments. The WET21 sediment sample contained arsenic and copper concentrations which ranked low within the site classification. Boron and zinc concentrations ranked mid-range within the site classification, and the vanadium concentration reported was among the highest for the entire sample set. Extractable cobalt was reported at slightly above the detection limit, one of only five sample sites with a reportable concentration. The boron and cobalt concentrations exceeded the mean values for soils and other surficial materials of the western U.S. by a factor of 1.7; other trace element concentrations were below the regional mean values.

Furnell WPA

Climatic setting. The net annual precipitation balance for the Furnell WPA (from the MAPS database) is -19 inches, showing Furnell to be the least evaporatively intense of the plains sampling sites. Monthly average precipitation for the Gold Butte climatic station shows a broad summer peak with a maximum in June. The 3-year moving averages for the Gold Butte station appears to show roughly cyclical peaks with a period of 6 to 11 years. The moving average has been mostly near or above the long-term mean since the mid 1980s; in 1993 (the year prior to sampling) the annual total exceeded the long-term mean by more than 10 inches.

Geologic setting. The Furnell WPA site is underlain by calcareous till deposited in a prominent end moraine complex. The moraine marks the terminus of a late Pleistocene glacial lobe which occupied the gap in the Sweet Grass Hills. Till underlying the sample site appears relatively loose-textured with a matrix of fine sand and silt.

Bedrock beneath the till cover is sandstone and shale of the late Cretaceous Eagle Formation and Claggett Shale, regionally intruded by the alkaline intrusive complex underlying the Sweet Grass Hills. There are producing and shut in natural gas wells within a few hundred meters of the site.

Hydrologic type. The Furnell site is a small glacial kettle lacking surface drainage at water levels represented by the samples analyzed. Shoreline features and drainage development indicate outflow from the pond occurs at pond stage roughly 3 feet higher than that observed in August 1994. Ground-water outflow may occur, based on topographic position and the character of underlying glacial sediments.

Basin characteristics. The Furnell site is very small but has an intermediate catchment to wetland area ratio among hydrologically similar sites. The basin has a relatively flat bottom and a maximum depth of approximately 1.5 feet at water levels observed in August 1994. The pond has two prominent slope breaks appearing to correspond to periods of higher stage; the upper feature probably relates to an upper stage controlled by surface outflow. The outflow channel is a grassy swale with poorly defined meander patterns shown by vegetation; outflow appears to have occurred relatively recently and may occur on a regular seasonal basis.

Water chemistry. The Furnell site contains water of a dilute calcium/potassium - bicarbonate character. The proportionately high potassium concentration is unusual among the sampled wetlands. Equilibrium calculations indicate moderate supersaturation with carbonate species.

Water column concentrations of trace elements were either below detection limits or (for arsenic and boron) near detection limits

and at the lower extreme for hydrologically similar sample sites.

Orthophosphorous and total phosphorous concentrations were near the lower end of the range for sample sites of this type. Nitrate and ammonium concentrations were both below detection limits; the total organic carbon concentration was intermediate among similar sites.

Chemical history. No previous measurements of chemical characteristics for this site (or nearby wetlands) are known. Specific conductance measurements collected in August 1994 (two months after sampling) showed a 45% seasonal increase during that period. Periodic spill at high pond stage and/or recharge to the ground water system maintain dilute water chemistry at this site.

Sediments. By contrast with the water column data, several trace elements in Furnell WPA sediments occur at intermediate to high concentrations compared to hydrologically similar sample sites. Elevated sediment concentrations of chromium, nickel, vanadium and zinc (none of which occurred above detection limits in the water column) probably relate to sources in the shales underlying the site, and suggest the geochemistry of this wetland is effective in sequestering the natural influx of metals to the wetland.

Gaffney Lake

Climatic setting. The net annual precipitation balance for Gaffney Lake derived from the MAPS database is -24 inches, toward the middle of the range of evaporative intensity for sites in this class. Based on analyses of evaporation pan data, this is a considerable underestimate Gaffney Lake's water deficit, and points out the need to view the MAPS estimates only as relative indicators of net site precipitation. Mean monthly precipitation for the Medicine Lake climatic station shows a pronounced June maximum. Annual totals for this station show apparent periodicity with a 5 to 7 year cycle. Throughout the 1980s, the 3-year running average remained below (often well below) the long-term average, recovering in the early 1990s. In 1993 (the year before sampling) precipitation exceeded the long-term average by more than 1 inch.

Geologic setting. Gaffney Lake occupies an irregular and modified depression in the sequence of late Pleistocene outwash sand and gravel forming the Clear Lake aquifer, near the contact with kame terrace(?) deposits to the south. The composite thickness of the outwash gravels is greater in the Gaffney-Medicine Lake vicinity than elsewhere along the Clear Lake outwash channel. Glacial sediments are underlain at depth by the early Tertiary Fort Union Formation.

Hydrologic type. Gaffney Lake is a natural depression receiving ground-water inflow from the Clear Lake aquifer. A system of ditches and control structures provides managed surface-water inflow from lower Lake Creek by way of "Lake 10" (U.S. Fish and Wildlife Service usage) and other ponds. Managed surface-water outflow occurs via Long Lake to Medicine Lake. Under unusually high stages of Medicine Lake, these flows may reverse, allowing inflow from Medicine Lake (with imported Big Muddy Creek water) to Gaffney Lake. Ground-water outflow to the Clear Lake aquifer and to Medicine Lake is inferred to occur under the typical stage conditions.

Basin characteristics. The natural surface catchment of Gaffney Lake is small relative to the area of the lake; without water imports, most of the inflow to the lake would be provided by ground water discharge. At management (preferred) stage, Gaffney Lake has an estimated volume of about 4700 acre-feet and an average depth of a little over 7 feet. In 1993 (the year of sampling) the lake elevation was more than 5 feet below management levels all year, with an estimated volume only about 25% of the management-level volume. From 1989 to 1992, Gaffney Lake's estimated water volume never exceeded 55% of the management-stage volume.

Water chemistry. At the time of sampling, water in Gaffney Lake was highly alkaline, "mesosaline", and sodium-sulfate/bicarbonate in composition. Equilibrium calculations reflect estimated parameter values and have no validity for this sample. The ammonium, orthophosphorous and total organic carbon concentrations

ranked mid-range among hydrologically similar sites, while the total phosphorous concentration was the highest of any sample site with surface drainage and among the highest for the entire sample set.

Gaffney Lake's arsenic concentration ranked among the highest in the sample set and in its classification. The reported boron concentration was among the highest for sample sites lacking surface water outflow. Most other trace element concentrations were below detection limits.

Chemical history. Previous water quality analyses from Gaffney Lake generally show more dilute conditions than at the time of the DHES sampling. Specific conductance measurements in September 1984 and August 1980 were 3100 and 4870 microsiemens/cm, compared to 10500 microsiemens/cm at the time of the DHES sampling. During 1994 and 1995 monthly monitoring of field water chemistry, specific conductance generally ranged from 2500 to 3000 microsiemens/cm; (a single March 1995 measurement of 310 microsiemens/cm seems likely to be either measurement error or the local effect of spring ice-melt.)

The dissolved oxygen concentration in Gaffney Lake dropped to a measured value of 4 milligrams per liter during the winter of 1995.

Sediments. The arsenic concentration in the Gaffney Lake sediment sample was among the lowest in the site classification. For the most part, concentrations of other trace elements were below analytical detection limits. The reported arsenic concentration was well below the mean value for soils and other surficial materials in the Western U.S.

Hailstone Reservoir

Climatic setting. The net annual precipitation balance for Hailstone Reservoir (from the MAPS database) is -28 inches, placing it among the most strongly evaporative of the sample sites. Average monthly precipitation for the Rapelje climatic station shows a strong May-June peak. The 3-year running average of total annual precipitation shows apparent periodicity, with 6 to 9 years between peaks. Between the early 1970s and 1992, the 3-year average remained mainly above the average for the period of record. Data for 1993 and 1994 were not recovered for this station.

Geologic setting. Hailstone Reservoir occupies a structurally controlled basin underlain by medium-to-fine-grained sandstone of an unidentified formation (Lennep Sandstone?) bearing intervals of oyster shell conglomerate with a sandy matrix. Surficial sediments within the lake basin include fine-grained, mucky silt, extensive areas of precipitated salts on low-gradient shorelines, and well-sorted, ripple-marked sand in higher-energy littoral areas.

Hydrologic type. Hailstone Reservoir is a managed impoundment which probably had a history as a natural wetland prior to the construction of the dam which now controls outflow. Although the reservoir has a spillway and has discharged water in the past, at the time of sampling in April 1993 and during follow-up investigations in October 1994, lake stage was more than 5 feet below the spillway crest. U.S. Fish and Wildlife Service personnel responsible for Hailstone Reservoir report that no spill has occurred since the early 1980s. For classification purposes, Hailstone Reservoir is considered to be effectively lacking surface discharge.

Basin characteristics. Hailstone reservoir has an intermediate ratio of catchment to wetland area when compared to hydrologically similar sample sites. Attempted sounding of the reservoir was terminated by the near-arrest of the surveyor; a single depth measurement of 6.5 feet is thought to be close to the maximum for the reservoir. Low topographic gradients around most of the reservoir imply highly transient shoreline positions as lake stage changes. The sampling site WET24 is along one of the steeper, comparatively less transient reaches of shoreline.

Active ground-water seepage through the dam supports a small flow in Cedar Creek immediately below the dam face, and provides for some export of solutes under the observed low-water conditions.

Water chemistry. When sampled in April of 1993, Hailstone Reservoir water was a "eusaline" sodium sulfate brine with low carbonate and bicarbonate concentrations. Mineral equilibria indicate substantial supersaturation with carbonate species and slight supersaturation with gypsum. [Possible errors in calcium, magnesium and alkalinity analyses render these saturation indices uncertain.]

Phosphorous concentrations in Hailstone Reservoir were in the mid-range for hydrologically similar sites, as were ammonium and total organic carbon concentrations.

Arsenic, boron, chromium and nickel concentrations were at or near the high end of ranges for hydrologically similar sample sites. Chromium and nickel concentrations in Hailstone Reservoir were higher than for any other sample site.

Chemical history. No previous chemical analyses are known for Hailstone Reservoir. Anecdotal observations indicate that the reservoir has been experiencing progressive salinization for a number of years, probably since the construction of the dam. The concentration and volume at which the reservoir solute load would be in approximate equilibrium with ground-water outflow is not known.

In October of 1994, specific conductance at the WET24 site was 59600 microsiemens/cm, a 35% increase over the conductance measured at the time of sampling in April 1993. At the same time, ground water discharging into Cedar Creek at the seepage face of the dam showed specific conductance of only 39700 microsiemens/cm. This salinity contrast may reflect dilution by comparatively dilute ground water (a nearby spring produces water with specific conductance of 1560 microsiemens/cm). Alternatively, the lower salinity may reflect reservoir seepage at times of more dilute lake chemistry.

Spatial variability in salinity within Hailstone Reservoir has not been measured but is probably not great under most circumstances due simple lake geometry and wind exposure.

Sediments. Trace element concentrations measured in Hailstone Reservoir sediments were for the most part below detection limits; those with detectable concentrations occur at low to moderate concentrations compared to hydrologically and regionally similar sites. Several trace elements prominent in the Halfbreed Lake sediment analysis and in the Hailstone Reservoir water column are below detection limits in Hailstone sediments. This contrast may reflect the physical character of sediments found at WET24; trace elements in solution may have a relatively low affinity for the reworked sand observed in the vicinity of the sampling site.

Halfbreed Lake

Climatic setting. The net annual precipitation balance for Halfbreed Lake (from the MAPS database) is -28 inches, placing it among the most strongly evaporative of the sample sites. Average monthly precipitation for the Rapelje climatic station shows a strong May-June peak. The 3-year running average of total annual precipitation shows apparent periodicity, with 6 to 9 years between peaks. Between the early 1970s and 1992, the 3-year average remained mainly above the average for the period of record. Data for 1993 and 1994 were not recovered for this station.

Geologic setting. Halfbreed Lake lies near the intersection of the Lake Basin fault zone and the trend of the Lake Basin anticline. Upland areas adjacent to the lake are scattered with noncalcareous sandstone float of an uncertain formation (Lennep Sandstone?)

The site is underlain by fine-grained, calcareous, plastic lake sediments with accumulations of organic debris at higher shoreline elevations.

Hydrologic type. Halfbreed Lake is a structurally controlled(?) depression, modified by ditching and impoundment, with controlled outflow.

Basin characteristics. Halfbreed Lake has a relatively high catchment to wetland ratio in comparison to hydrologically similar sample sites. At low water levels, the northeastern basin of the irregularly shaped lake is separated from the main basin, allowing distinct salinity to develop. A distinct "full pool" shoreline is developed at an elevation approximately 2.3 feet above the lake stage at the time of sampling, and approximately 1.7 feet above lake stage at the time of follow-up observations in October 1994. This shoreline feature may be controlled by the lake's outlet structure.

Water chemistry. At the time of sampling, Halfbreed Lake contained "mesosaline" sodium sulfate water. Equilibrium calculations indicate substantial oversaturation with carbonate species and slight undersaturation with gypsum. [Estimated calcium/magnesium ratios and uncertain carbonate and bicarbonate concentrations reduce the usefulness of these indices.]

Nutrient concentrations were unremarkable in comparison to hydrologically similar sites. Along with other sample sites in the region, Halfbreed Lake water contained copper, chromium and nickel concentrations at or near upper end of the sampled range.

Chemical history. No water chemistry data prior to the April 1993 DHES sampling are known from Halfbreed Lake. In October 1994, specific conductance at the WET25 site was only 37% of the conductance at the time of the 1993 sampling, probably reflecting flushing during the wet spring and summer of 1993. Historic water

levels shown by shoreline development are inferred to reflect still more dilute water chemistry at times of higher throughflow. The water quality of inflow received by Halfbreed Lake is probably affected by saline seeps in the Cedar Creek drainage and by the evaporative salinization of water stored upgradient in Hailstone Reservoir.

Sediments. Sediment concentrations of copper, boron, chromium, nickel and zinc were found near at or near the upper end of their ranges for hydrologically similar sample sites. Copper exceeded mean soil values for the western U.S. by a factor of about 2; boron by a factor of about 3, and nickel and zinc by factors of about 1.5. The chromium concentration was below the regional mean soil concentration.

Hewitt Lake National Wildlife Refuge

Climatic setting. The net annual precipitation balance for the Hewitt Lake site (from the MAPS database) is -28 inches, placing the site at the more evaporative end of the range shown by sites in this classification. Monthly mean precipitation for the Malta 7NE climatic station shows a broad summer peak with a maximum in May; the Malta climatic station, with a longer period of record but farther from Hewitt Lake, shows a pronounced June maximum. Annual totals for the Malta 7NE station, shows the years 1988 to 1992 below the average for the period of record. The total for 1993 (the year prior to sampling) exceeded the average for the period of record by about 2.5 inches.

Geologic setting. The Hewitt Lake catchment is underlain by the Late Cretaceous Claggett Shale. Although the area is within the extent of Pleistocene glaciation, glacial deposits in the immediate Hewitt Lake area may be thin or absent. Hewitt Lake lies near the apex of the Bowdoin structural dome, apparently the trap for natural gas reservoirs exploited by the well field surrounding the refuge.

Hydrologic type. Hewitt Lake is an impounded reservoir with a surface water outlet structure; Hewitt Lake is at the downstream end of a series of intermittent natural lakes and ponds, and may have a pre-impoundment history as a smaller natural basin. Hewitt Lake has been dry or essentially dry during some recent drought years. The history of discharge from the Hewitt Lake outlet structure is not known.

Basin characteristics. Hewitt Lake's catchment to wetland area ratio ranks in the mid-range among sample sites in its classification. Depth and volume of the Hewitt Lake basin are not known. Based on the geologic setting, ground water is not thought to be an important contributor to Hewitt Lake's water budget. Storage in (and evaporation from) intermittent lakes and ponds in the Hewitt Lake catchment probably influence the runoff characteristics of the basin.

Water chemistry. At the time of sampling, Hewitt Lake contained alkaline, "oligosaline" water of sodium sulfate character. Mineral equilibria indicate moderate oversaturation with respect to carbonate phases. The nitrate concentration was below detection limits, and the ammonium concentration ranked mid-range among sites in the same classification. The orthophosphorous concentration ranked mid-range for sample sites of this classification, but the total phosphorous concentration ranked near the upper end of the range shown by the sample set overall.

The Hewitt Lake water column contains an enriched suite of trace metals relative to other sites of the glaciated plains, looking more like sample sites of south-central Montana in this respect. Concentrations of chromium, copper, iron, lead and zinc rank at the

top of the ranges shown by these elements. Arsenic and boron concentrations rank mid-range within this site's classification.

Chemical history. No previous water chemistry data from this site are known.

Sediments. Extractable concentrations of arsenic, boron, copper, iron, nickel, vanadium and zinc rank mid-range among sites within this classification. Most other trace elements were reported to be below detection limits. Only boron exceeded the mean value for soils and other surficial materials of the western United States.

Homestead Lake

Climatic setting. The net annual precipitation balance for Homestead Lake derived from the MAPS database is -25 inches, toward middle of the range of evaporative intensity for sites in this class. Based on analyses of evaporation pan data, this is a considerable underestimate Homestead Lake's water deficit, and points out the need to view the MAPS estimates only as relative indicators of net site precipitation. Mean monthly precipitation for the Medicine Lake climatic station shows a pronounced June maximum. Annual totals for this station show apparent periodicity with a 5 to 7 year cycle. Throughout the 1980s, the 3-year running average remained below (often well below) the long-term average, recovering in the early 1990s. In 1993 (the year before sampling) precipitation exceeded the long-term average by more than 1 inch.

Geologic setting. Homestead Lake lies along the margin of the Big Muddy Creek Valley; permeable gravel aquifers (glacial and preglacial?) underlie portions of the lake and are shown by groundwater monitoring data to be in hydrologic communication with it.

Hydrologic type. Homestead Lake is a modified and managed impoundment with controlled inflows from Big Muddy Creek and controlled outflow back to Big Muddy Creek, as well as internal routing of water within management subunits of the lake. The lake is hydrologically connected to regional gravel aquifers; the direction of water movement between aquifers and the lake is uncertain, and may be influenced by diversions of surface water into Homestead Lake. Portions of Homestead Lake may have existed as a seasonal water body prior to the construction of dikes and diversions.

Basin characteristics. Homestead Lake receives inflow both from the natural catchment areas or Sheep Creek and Lost Creek to the east and from the diversion of Big Muddy Creek. The ratio of the natural western catchment to the wetland area ranks mid-range within its classification; most lake inflow comes from the Big Muddy diversion, however. Management structures include dikes separating lake subunits which are dependent on natural flows in Sheep and Lost creeks. These were reported to be dry throughout 1993, the year of sampling.

The reported capacity of Homestead Lake at "management elevation" is 8216 acre-feet, with an average depth between 6 and 7 feet. Large water deficits were reported for Homestead Lake throughout the 1989-1993 period; at the beginning of 1993 the Homestead Lake complex reportedly held only 122 acre-feet of water. High flows in July of 1993 (postdating the DHES sampling) allowed the diversion of an estimated 6525 acre-feet over a short period. Most of this water was impounded within the northern management unit of the lake, within which the WET27 site is situated.

Water chemistry. At the time of sampling, water at the WET27 site

was alkaline, "oligosaline" and sodium-sulfate/bicarbonate in composition. (Salinity, relative ion concentrations and nutrient levels may have changed substantially shortly after sampling, with the rapid importation of a comparatively large volume of newly diverted Big Muddy Creek water.) Mineral equilibria indicate substantial oversaturation with respect to carbonate phases.

The nitrate concentration was below detection limits and the reported ammonium concentration ranked toward the low end of the range shown by sites in this classification. The orthophosphorous concentration ranked mid-range within the site classification, while the total phosphorous concentration (sampled in 1994, the year following sampling of other parameters) was near the high end of the range shown by sample sites in this class. The total organic carbon concentration was low in comparison to similar sites.

Arsenic and boron concentrations ranked mid-range among sites of this classification. Chromium and lead were reported at the detection limit or slightly above, making WET27 one of the few sites in this class with reportable concentrations of these elements in the water column.

Chemical history. No water chemistry prior to the 1993 DHES sampling are known. Since 1994, the Fish and Wildlife Service has been monitoring field water chemistry parameters. The northern end of Homestead Lake has shown a range of specific conductance from over 2500 microsiemens/cm (July of 1994) down to 288 microsiemens/cm in March of 1995, following diversion of dilute runoff from the Big Muddy. Specific conductance was higher on all occasions in the southern lake basin; this is probably typical of conditions in Homestead Lake. The measured dissolved oxygen concentration in January of 1995 was 1.32 mg/l, showing near-depletion of oxygen under winter ice cover.

Sediments. Extractable concentrations of arsenic, copper and iron were found to be low to moderate in comparison to sample sites classified with WET27. Most other trace element concentrations were below detection limits. None exceeded mean values for soils of the western United States.

Hoskins Lake Research Natural Area

Climatic setting. The net annual precipitation balance for Hoskins Lake (from the MAPS database) is 7 inches, placing the site among the two wettest low-elevation sites in the sample set. Average monthly precipitation for the Troy 18NE climatic station shows a winter peak with a maximum in November. The records of annual total precipitation for the station are incomplete; available records from 1980 to 1991 show modest deviations from the average in both directions.

Geologic setting. Hoskins Lake occupies a glacially eroded trough paralleling the Yaak River valley and following the trace of one of a series of north-trending normal faults; preferential erosion along the fault may have influenced the location and orientation of the lake basin. The lake basin is underlain by paludal, lacustrine and (probably) glacial deposits of undescribed character. The underlying bedrock is composed of the Wallace Formation of the Proterozoic-aged Belt series; the Wallace Formation is dominantly argillaceous in composition but includes a significant calcareous component. Locally, calcareous interbeds in the Wallace Formation are described as frequently pyritic.

Hydrologic type. The upper open-water portion of Hoskins Lake (sometimes known as Hoskins Pond), where the WET28 site is located, has a discrete surface water outflow to Hoskins Lake but no channelized surface water inflow. Hoskins Lake itself has surface water drainage to the Yaak River. The outflow from Hoskins Pond has been described as intermittent, but no data regarding its flow characteristics are known.

Basin characteristics. Hoskins Lake and Hoskins pond occupy a single linear bedrock basin with a veneer of glacial(?) and Holocene sediments, separated by a minor topographic high and a vegetated wetland surface. The catchment to wetland area ratio is mid-range for Rocky Mountain sites; local relief is steep. The maximum depth reported for Hoskins Pond is 8.5 meters (27.5 feet). Based on topographic position, the lake basin may receive ground-water discharge from the Belt series bedrock. The dilute water chemistry suggests ground-water to be a minor hydrologic input, however.

Water chemistry. Hoskins Pond exhibits mildly alkaline, very dilute calcium-bicarbonate water. For a site of such dilute chemistry, WET28 shows an unusually high ratio of sulfate to bicarbonate, possibly reflecting the presence of sulfide minerals (pyrite) in the local Wallace Formation outcrops. Equilibrium calculations indicate substantial undersaturation with respect to carbonate minerals.

The nitrate and total organic carbon concentrations at WET28 ranked mid-range among Rocky Mountain sites, while the ammonium concentration was below detection limits. The orthophosphorous

concentration was at the lower end of the range shown by the entire sample set; the total phosphorous was not analyzed.

The Hoskins Pond sample showed an iron concentration ranking mid-range among sites in it's classification. Most other trace element concentrations were below detection limits.

Chemical history. No other quantitative water chemistry data are known from Hoskins Pond. A partial analysis of water from Hoskins Lake proper, collected in 1994, shows similarly dilute, mildly alkaline characteristics. Generally, this site can be inferred show less variability in water chemistry than most of the sample sites.

Sediments. The concentrations of extractable copper and iron ranked in the mid-range for Rocky Mountain sites, while arsenic and zinc were reported toward the lower end of their respective ranges for sites classified with Hoskins Lake. Most other trace element concentrations were below detection limits. The copper concentration exceeded the mean value for soils of the western United States by a factor of 1.2; arsenic and zinc concentrations were below their respective regional mean values.

Indian Meadows Proposed Research Natural Area

Climatic setting. The net annual precipitation balance for Indian Meadows (from the MAPS database) is -3 inches. This places the site toward the wetter end of the range shown by the sample sites and mid-range among sites similarly classified. Average monthly precipitation for the Lincoln Ranger Station climatic station shows a bimodal distribution, with a primary May maximum and a secondary November peak. (The sample site is at a considerably higher elevation than Lincoln and probably does not reflect the same seasonal distribution of precipitation.) Annual total precipitation for the Lincoln Station shows the 3-year running average exceeding the long-term average most years from the mid-1970s to the mid-1980s, and falling short of the long-term average most years since the mid-1980s. In 1992, the year preceding the DHES sampling, total precipitation fell short of the long-term average by about 4.5 inches. In 1993 total precipitation exceeded the average by about 5 inches.

Geologic setting. The Indian Meadows area is underlain by glacial deposits of undescribed character. Inferred source areas for till or other glacial deposits include extensive exposures of the Helena Formation, a calcareous component of the Proterozoic-aged Belt series of metasediments. In the immediate area of Indian Meadows, glacial deposits are underlain by Tertiary-aged volcanic, volcanoclastic and sedimentary rocks. Similar volcanic rocks in nearby areas host gold and accessory mineralization, and similar mid-Tertiary sedimentary rocks are described as pyritic in nearby areas.

Hydrologic type. Indian Meadows occupies a glaciated topographic trough capturing snowmelt, runoff and (probably) local ground water recharged on ridges to the north and south. The Indian Meadows pond sampled at site WET29 has a channelized surface water outlet but lacks channelized inflow.

Basin characteristics. The Indian Meadows site has catchment to wetland area ratio ranking toward the low end of the range shown by Rocky Mountain sites. Local relief within the small catchment is relatively high. Ground-water flow is probably very local in nature. The water depth of the site is unknown.

Water chemistry. The WET29 site exhibits dilute, near-neutral calcium bicarbonate chemistry. Equilibrium calculations indicate undersaturation with carbonate minerals. Nitrate and ammonium concentrations were below detection limits, orthophosphorous ranked mid-range among Rocky Mountain sites, and total organic carbon ranked toward the upper end of the range shown by this class of sample sites.

The Indian Meadows site contains comparatively high concentrations of several trace elements. Concentrations of arsenic, lead, copper and zinc all rank near the top of the ranges shown by Rocky

Mountain sites. Indian Meadows was one of only 5 sample sites for which water-column selenium was reported.

Chemical history. No other chemical data known to be from this site are available. A partial chemical analysis collected somewhere in Indian Meadows in 1987 showed a slightly more dilute character than the DHES sample. The actual location of this sampling location is uncertain, however. Generally, the chemical variability expected of this site is low.

Sediments. The concentrations reported for arsenic, copper, iron and zinc ranked mid-range for sites in the Rocky Mountains. Most other trace elements were below reporting limits. Arsenic exceeded the mean soil value for the western United States by a small amount, while copper and zinc were less than the regional mean values.

Jarina Waterfowl Production Area

Climatic setting. The net annual precipitation for the Jarina WPA site (from the MAPS database) is -9 inches, making Jarina the least evaporative of sample sites within its classification. Note, however, that the Jarina site is in an area of very steep precipitation gradients which may not be represented well by the MAPS cell averages. Monthly average precipitation for the Blackleaf Canyon climatic station shows a relatively strong May-June peak with wide ranges between monthly minimum and maximum values. Annual totals for the 44 year period of record at the Blackleaf site show an apparent periodicity in precipitation with a wavelength of 5 to 7 years (shown by the 3-year running average). Precipitation for 1993, the year prior to the sample collection, exceeded the average for the period of record by approximately 8 inches.

Geologic setting. The Jarina WPA and surrounding areas are underlain by calcareous till deposited by an alpine glacier or glaciers terminating on the western edge of the plains. Shoreline areas display variable sediment character, apparently controlled by prevailing wind directions; the sample site proper is on the westerly (upwind) shore, and is underlain by fine-grained organic-rich sediments. Easterly (downwind) shores of the sample site and nearby lakes tend to be underlain by coarse sand and gravel.

Bedrock in the area is sandstone and mudstone from unspecified Late Cretaceous formations. The overlying till is thin to absent in places, exposing occasional sandstone outcrops, some of which appear to be associated with ground-water seeps.

Hydrologic type. The Jarina WPA site is a glacial depression lacking surface drainage at current water levels. Strandlines of unknown age indicate periods in the past when water levels have been controlled by drainage to the southeast (to Sheep Creek). During such times, water depths were 3 to 4 feet greater than those measured in 1994 and lake volume may have been greater by as much as a factor of 5(?).

Basin characteristics. The Jarina WPA site has a relatively small surface catchment with respect to wetland area and volume. The basin is shallow throughout, with a maximum measured depth in August 1994 of 2.8 feet and an average depth of about 2 feet or less. The cluster of numerous small lakes and wetlands surrounding the sample site display highly disjunct water chemistry; surveyed water bodies within a 2 square mile area ranged from 452 to >50,000 microsiemens/cm in specific conductance. More saline sites are typically underlain by unidentified evaporitic minerals; some lakes were desiccated in 1994. Construction of the berm supporting the Birch Creek road isolated the northernmost end of the basin from the remainder of the sample site. However, the presence of a high-water outlet at the opposite (southeastern) end of the basin effectively prevents the road from exerting a major influence on water budgets of the sample site.

Water chemistry. The Jarina WPA site exhibits "oligosaline" magnesium-sulfate water chemistry. Water column trace element and nutrient concentrations are comparable to regionally and hydrologically similar sites. Mineral phase equilibrium calculations indicate the water column is supersaturated with carbonate phases and essentially in equilibrium with gypsum. Calcareous crusts were observed riming littoral sediments; authigenic gypsum was not observed. The magnesium-sulfate composition and high gypsum saturation in a site of moderate salinity are unusual within the DHES sample set.

A seep discharging from Cretaceous sandstone of unknown formation in a neighboring lake basin is proportionately much higher in sodium and lower in total dissolved solids.

Chemical history. No chemical data predating the DHES sampling of this site are known. Conductivity measurements from August of 1994 are approximately 33% higher than during the site inventory sampling in June of 1994. Substantially increased lake volume and regular surface outflow in the past can be inferred from erosional shoreline features. Salinity would be expected to be much lower under such hydrologic conditions.

Sediments. Boron, iron, nickel, selenium and zinc concentrations are near the upper extreme for regionally and hydrologically similar sample sites. Boron, nickel, zinc, arsenic and selenium exceed regional mean soil concentrations by factors of 2 to 5, with boron exhibiting the highest relative enrichment relative to regional values.

Kingsbury Lake WPA

Climatic setting. The MAPS database indicates a net annual precipitation balance of -24 inches. This is near the less evaporative end of the range shown for hydrologically similar sample sites, reflecting somewhat higher precipitation than over most plains sites. Monthly average precipitation for the nearby Geraldine station shows a pronounced May-June peak. 3-year running averages since the mid 1970's have mostly remained near or above the long-term average, but totals from 1990 through 1992 (the latest year of compiled record) were below the long-term average.

Geologic setting. Kingsbury Lake occupies a position immediately south of the limit of maximum Pleistocene glacial advance. Kingsbury and nearby lakes are interpreted to lie along ice-marginal drainage channels developed along the glacial margin. The lake basin is underlain by sandstones and shales of the Colorado Group, intruded by dikes connected to the shonkinite intrusion of the Highwood Mountains to the south. Surficial sediments include extensive chemical precipitates, fine-grained organic-rich and reduced lakebed silt and clay, and poorly sorted littoral sand and gravel along winnowed shorelines.

Hydrologic type. Kingsbury Lake is a glaciofluvial(?) depression lacking surface drainage at historically experienced water levels. Significant ground water discharge from the basin is considered unlikely due to topographic position, the character of basin geology, and high lake salinity.

Basin Characteristics. Kingsbury Lake is a relatively large playa with a low catchment to wetland area ratio in comparison to hydrologically similar sample sites. The lake basin describes a dogleg, apparently controlled in part by resistant outcrops of intrusive rocks. Most of the inflow to the lake is contributed by Alder Creek, which enters western end of the lake. Strong evaporative conditions, a low volume to surface area ratio (lake depths are reported to be less than 3 feet), and restricted circulation into the eastern arm of the lake create substantial salinity gradients within the lake under the observed conditions.

Water chemistry. Water at WET31 at the time of sampling was a highly saline sodium sulfate type with low bicarbonate and carbonate concentrations. Salinity at the sampling site was near the upper extreme for hydrologically similar settings in the sampling network. Equilibrium calculations indicate supersaturation with carbonate species and slight supersaturation with gypsum. Active gypsum(?) precipitation was observed at the sampling site (under somewhat more concentrated conditions than represented by the sample analysis.)

Water column concentrations for arsenic, boron, and iron were the highest among sampling sites of this type. Chromium concentrations are characteristically elevated for sample sites of this type.

Orthophosphorous and total phosphorous are among the highest of the sampled sites, and at the upper extreme of hydrologically similar sites. Nitrate and ammonium concentrations were both below detection limits. The total organic carbon concentration was also the highest among this site type.

Chemical history. No previous quantitative chemical analyses are known for Kingsbury Lake. U.S. Fish and Wildlife Service records contain reference to two reported specific conductance measurements of 32,000 and 39,000 microsiemens/cm, one dating from 1981 and the other date unrecorded. Specific conductance in the eastern lake arm (which includes WET31) exceeded 100,000 microsiemens per centimeter in August 1994, indicating a twofold or greater seasonal increase in specific conductance over the date of sample collection two months earlier. It is likely that at least the eastern lake arm has desiccated entirely within historic times. Elevated relict shorelines indicate much more dilute conditions have prevailed at times in the recent geologic (and possibly historical) past. The general area is prone to developing saline seeps in cropped areas, which possibly have contributed to the lake's present salt load.

Spatial salinity gradients were observed in both horizontal and vertical dimensions. In August of 1994, specific conductance ranged from greater than 100,000 microsiemens/cm in the hypersaline eastern arm down to 23,100 microsiemens/cm along the southern shore of the western arm. It is likely that water near the Alder Creek inflow was considerably more dilute still. Among vegetation mats along the southern shore, a substantial vertical salinity gradient was observed in shallow water, with specific conductance near the lake bottom exceeding that at the surface by approximately 30%.

Sediments. Kingsbury Lake sediments include a large component of chemical precipitates, including both carbonates (inferred from HCl reactivity and mineral saturation indices) and sulfates (inferred from saturation indices and euhedral hand specimens). Bottom sediments in the eastern arm are extremely sticky and reduced, with a bituminous appearance beneath an oxidized surface layer.

Extractable concentrations of boron are at the upper extreme for hydrologically similar sites; other trace elements are typically present in concentrations within the range of other hydrologically and regionally similar sites. Boron exceeds the regional soils average by a factor of six; zinc and copper exceed regional soils means by a few percent. Other trace element concentrations are below the regional soils means for those constituents.

Kleinschmidt Lake WPA

Climatic setting. The net annual precipitation balance for the Kleinschmidt Lake site (from the MAPS database) is -18 inches, placing the site toward the middle of the range for hydrologically and regionally similar sites. Monthly average precipitation for the Ovando 9 SSE climatic station shows a bimodal distribution, with a primary June peak and a secondary January peak. The 3-year moving average of total annual precipitation remained below (often considerably below) the long-term average from the mid-1970s through 1993. The total precipitation for 1993 (the year prior to sampling) was very near the long-term average.

Geologic setting. Kleinschmidt Lake occupies an irregular basin within a terminal moraine complex deposited by a glacier advancing down the North Fork of the Blackfoot River during the late Pleistocene. Permeable outwash gravels dating from the retreat of the North Fork glacial lobe forms Kleinschmidt Flat to the northeast; advance outwash deposits may underlie the till forming the end moraine complex. Tertiary valley-fill sediments underlie glacial deposits at an unknown depth.

Hydrologic type. Kleinschmidt Lake lies in glaciated terrain with generally poorly integrated drainage, but has channelized inflow and outflow. The outflow elevation was altered by a wetland enhancement project in the mid-1980s(?). Relatively low salinity indicates that discharge from the lake occurs frequently. Ground-water relationships are undescribed.

Basin characteristics. Kleinschmidt Lake receives inflow from nearby Brown's Lake via a small drainage meandering through an area of small internally drained depressions. Most of the contributing catchment is upgradient of Browns Lake. The timing and quantity of inflow received by Kleinschmidt is influenced by residence time of the larger Brown's Lake. Prior to alteration of the outflow, the estimated volume of the lake was 1083 acre-feet, with an average depth on the order of 5 feet. The present lake depth and volume are uncertain.

Water chemistry. At the time of sampling, Kleinschmidt Lake contained relatively dilute, highly alkaline magnesium-bicarbonate water. Mineral equilibria indicate substantial oversaturation with respect to carbonate phases. Ammonium and nitrate concentrations were below detection limits, and the orthophosphate concentration was near the low end of the range shown for sites in this class. The total organic carbon concentration ranked mid-range within the site class. The total phosphorous concentration was not determined.

Arsenic and iron concentrations ranked mid-range among sites classed with Kleinschmidt Lake; the selenium concentration made Kleinschmidt Lake one of only 5 sample sites with reportable water column values for this element.

Chemical history. No previous laboratory water chemistry data are known for Kleinschmidt Lake. In the late 1950s, dissolved oxygen monitoring was performed as part of a fishery enhancement effort. Wintertime dissolved oxygen concentrations dropped to the 1-2 milligram per liter range at that time. Changes to lake volume and depth since then may have altered the lake's wintertime dissolved DO.

Sediments. Arsenic was reported at a concentration ranking the site toward the low end of the range shown by sites in the same class. Copper, iron and zinc concentrations ranked mid-range in comparison to similar sites. None exceeded the mean values for soils and other surficial materials of the western United States.

LaFoe Lake

Climatic setting. The net annual precipitation balance for LaFoe Lake (from the MAPS database) is approximately 8 inches. This makes LaFoe Lake the wettest of the lowland sites among the sample set. Mean monthly precipitation for the Libby Ranger Station climatic station (at a lower elevation than the WET33 site) shows a bimodal distribution, with a broad primary winter maximum and a secondary June peak. Annual totals for the Libby station show a 3-year running average since 1950 generally meeting or exceeding the average for the period of record, with the exception of the 1977 to 1982 period. Annual precipitation in 1993 (the year prior to sampling) met the long-term average for the station.

Geologic setting. LaFoe Lake and the contributing drainage basin are underlain by the calcareous Wallace Formation of the Proterozoic Belt series. Alpine glaciers occupied nearby headwater areas, but their down-valley extent is uncertain. Glacial and other surficial sediments overlying bedrock are undescribed, but inferred to be relatively thin. LaFoe Lake lies over the trace of the Quartz Creek Fault, a north-trending normal fault downdropped to the west.

Hydrologic type. LaFoe Lake occupies a small depression of uncertain origin, fed by intermittent(?) streamflow and drained by a perennial(?) stream.

Basin characteristics. The LaFoe Lake drainage basin features high local relief and a comparatively high catchment to wetland area ratio relative to other western sample sites. The lake itself lies near a low drainage divide which may be controlled in some fashion by the Quartz Creek Fault, the trace of which passes through this gap.

Water chemistry. The water chemistry of LaFoe Lake is dilute, near-neutral and calcium-bicarbonate in composition. Mineral equilibria indicate undersaturation with respect to carbonate phases. The ammonium and phosphorous (total and orthophosphorous) concentrations rank toward the upper end of the ranges shown by Rocky Mountain sites; The total organic carbon concentration ranks mid-range among Rocky Mountain sites.

Iron and aluminum concentrations rank near the high end of the range shown by Rocky Mountain sites; the reported copper concentration ranked mid-range, and most other trace element concentrations were below detection limits.

Chemical history. One previous (partial) chemical analysis is known from LaFoe Lake. This sample, collected in June of 1987, had a specific conductance of only 62 microsiemens/cm, about one-third the value recorded at the time of the DHES sampling. This may provide some idea of the kind of seasonal variation in salinity expected at this site from early to late summer. No analyses of

trace elements or micronutrients were included in this analysis. Generally, the rapid flux of water through this site implied by the moist climatic setting and high catchment to wetland ratio would be expected to maintain dilute water chemistry.

Sediments. The extractable arsenic concentration reported for LaFoe Lake is one of the lowest for the entire data set. Boron, iron, selenium and zinc concentrations rank mid-range among Rocky Mountain sites. Most other trace elements were below detection limits.

The selenium concentration reported exceeded the mean value for soils and other surficial materials of the western U.S. by a factor of 1.7; other reported values were below their regional soil means.

Lahrity Lake

Climatic setting. The net annual precipitation balance for the Lahrity Lake site (from the MAPS database) is -17 inches, placing the site toward the middle of the range for hydrologically and regionally similar sites. Monthly average precipitation for the Ovando 9 SSE climatic station shows a bimodal distribution, with a primary June peak and a secondary January peak. The 3-year moving average of total annual precipitation remained below (often considerably below) the long-term average from the mid-1970s through 1993. The total precipitation for 1993 (the year prior to sampling) was very near the long-term average.

Geologic setting. Lahrity Lake occupies a glacial ice-block depression (kettle) in till (and other glacial sediments?) deposited by ice advancing into the Ovando Valley from the Monture Creek drainage. The adjacent bedrock outcropping of Monture Hill is a prominent resistant knob underlain by the Snowslip Formation of the Proterozoic Belt series. The Monture Creek source area for the glacial deposits in the area includes large exposures of the calcareous and dolomitic Helena Formation.

Inspection of the glacial sediments surrounding Lahrity Lake shows abundant cobbles and boulders in a calcareous silty matrix.

Hydrologic type. Lahrity Lake is a glacial depression lacking surface drainage at present water levels. Strandlines represented by beach erosion features indicate water levels which may have allowed surface water discharge. High salinity indicates that ground-water outflow is restricted, allowing accumulation of solutes.

Basin characteristics. Lahrity Lake is a steep-sided basin with minimal surface catchment area relative to the size of the lake; the ratio of catchment to wetland area ranks near the bottom of the range for the entire sample set. Additional areas of small closed basins surrounding Lahrity Lake may contribute ground-water inflow. Irregular knobs of till within the lake basin suggest deposition as ablation debris in a region of stagnant ice.

Measured water depths at the time of sampling ranged up to 11.5 feet; average depth was on the order of 6 feet and lake volume was estimated to be about 150 acre-feet (or 6.5 million cubic feet.) The sampled lake level was approximately 10 feet below the base of a prominent erosional shoreline feature and approximately 13.5 feet below the stage which would allow lake outflow to the southwest. At these lake stages, lake volume probably was several-fold greater than at the time of sampling, as low-gradient areas at the north end of the lake flood.

Water chemistry. Presently, Lahrity Lake contains highly alkaline, "polysaline" sodium/potassium-sulfate brine virtually depleted in calcium; the proportional potassium concentration is uniquely high

for the saline sample sites. Equilibrium calculations indicate oversaturation with carbonate phases. The ammonium and total organic carbon concentrations are among the highest for western Montana sample sites (as are those for the adjacent WET35 site) while the total and orthophosphorous concentrations rank mid-range among sites in the same class.

The arsenic concentration is the highest among western sites, and is exceeded only by two hypersaline northeastern sampling sites. Copper and iron concentrations rank toward the middle of the range shown by sites in this class; most other trace element concentrations were reported to be below detection limits. However, interferences led to higher detection limits than typical for several elements.

Chemical history. No other quantitative chemical data for Lahrity Lake are known. Field measurements collected in July 1993 showed a pH of 9.92 and specific conductance > 20,000 microsiemens/cm. Geomorphic indicators imply that Lahrity Lake has probably spilled water during past climatic conditions. At such times, and at intermediate lake stages where the solute load is diluted, salinity can be much lower than during the modern observations.

Sediments. Littoral sediments are composed of a gelatinous, highly organic and reduced (H₂S generating) muck up to 1 foot in depth, overlying a firm cobbly surface of till.

Among western sample sites, only mine-impacted sediments showed higher concentrations of arsenic. Boron, copper, iron, selenium and zinc concentrations ranked toward the middle of the ranges shown for similar sites. The arsenic concentration exceeded the mean value for western United States soils by a factor of 5. Boron and selenium exceeded mean regional values by factors of 1.4 and 1.7, respectively; other trace element concentrations were below their regional mean soil concentrations.

Lahrity Lake Southwest wetland

Climatic setting. The net annual precipitation balance for the Lahrity Lake Southwest site (from the MAPS database) is -17 inches, placing the site toward the middle of the range for hydrologically and regionally similar sites. Monthly average precipitation for the Ovando 9 SSE climatic station shows a bimodal distribution, with a primary June peak and a secondary January peak. The 3-year moving average of total annual precipitation remained below (often considerably below) the long-term average from the mid-1970s through 1993. The total precipitation for 1993 (the year prior to sampling) was very near the long-term average.

Geologic setting. Lahrity Lake Southwest occupies a shallow glacial ice-block(?) depression in till (and other glacial sediments?) deposited by ice advancing into the Ovando Valley from the Monture Creek drainage. The adjacent bedrock outcropping of Monture Hill is a prominent resistant knob underlain by the Snowslip Formation of the Proterozoic Belt series. The Monture Creek source area for the glacial deposits in the area includes large exposures of the calcareous and dolomitic Helena Formation.

Inspection of the glacial sediments surrounding Lahrity Lake shows abundant cobbles and boulders in a calcareous silty matrix.

Hydrologic type. The Lahrity Lake southwest site is a relatively shallow glacial depression with at least seasonal surface water outflow. The outlet elevation prevents water levels in the wetland from rising substantially above that observed at the time of sampling. The wetland surface was approximately 7.9 feet higher than the surface elevation of adjacent Lahrity Lake, possibly restricting ground-water outflow from Lahrity Lake to the south.

Basin characteristics. The Lahrity Lake Southwest wetland appears to capture a larger area of surface drainage than Lahrity Lake proper, and has a higher catchment to wetland area ratio. Surface drainage and low volume (estimated maximum depth of 3-5 feet) imply relatively rapid flux of water and solutes through the site when compared to Lahrity Lake. Head relationships preclude this site from receiving ground-water outflow influenced by the Lahrity Lake brine.

Water chemistry. At the time of sampling, WET35 exhibited moderately alkaline "oligosaline" water lacking strongly dominant cation characteristics. Calcium, magnesium, sodium and potassium concentrations (in meq/l) were all within a factor of five of each other - an unusual distribution among the sample sites. CO₂ species (bicarbonate and carbonate) dominate the anion distribution. Equilibrium calculations indicate substantial oversaturation with carbonate minerals.

The ammonium concentration reported for WET35 was the highest of any of the sample sites. Total organic carbon, orthophosphorous

and total phosphorous concentrations were also very high, ranking at or near the top of the ranges shown for sites in the same classification. Most nutrients at this site are conspicuously high for settings with surface drainage and without very high salinity.

The arsenic concentration reported for WET35 was very high, exceeded only at three highly alkaline and saline sample sites. The iron concentration ranked mid-range among similar sites, and copper (reported at the detection limit) ranked toward the lower end of the range for sites of this class. Other trace element concentrations were reported below detection limits.

Chemical history. No other quantitative chemical data from this site are known. Field parameters measured in June of 1993 showed higher pH (9.04; 8.3 during the DHES sampling) and considerably lower specific conductance (775 microsiemens/cm; 2640 during the DHES sampling.) Surface outflow and comparatively high fluid flux through the basin are expected to limit the range of salinity at this site. The DHES analysis, collected at the end of a dry summer, may represent concentrations near the upper end of the expected range for this site.

Sediments. The wetland basin is underlain by 1 foot or more of peaty organic sediments with clots of apparent authigenic sediments (marl?). the selenium concentration ranked toward the upper end of the range for similar sites; arsenic and boron concentrations ranked toward the mid-range for sites in this classification, and iron and zinc concentrations ranked at the bottom of their respective ranges, with iron a significant low-end outlier among intermontane valley sites. Most other trace element concentrations were below detection limits.

Arsenic and selenium concentrations exceeded the mean concentrations for soils and other surficial materials of the western United States by factors of 2.4 and 1.7, respectively. Other trace element concentrations reported were below the regional mean values for soils.

Lake Bowdoin Inlet

Climatic setting. The net annual precipitation balance for Lake Bowdoin (from the MAPS database) is -28 inches, placing the Bowdoin sites at the more evaporative end of the range shown by sites in this classification. Monthly mean precipitation for the Malta 7NE climatic station shows a broad summer peak with a maximum in May; the Malta climatic station, with a longer period of record but farther from Lake Bowdoin, shows a pronounced June maximum. Annual totals for the Malta 7NE station, shows the years 1988 to 1992 below the average for the period of record. The total for 1993 (the year prior to sampling) exceeded the average for the period of record by about 2.5 inches.

Geologic setting. The natural catchment of Lake Bowdoin is underlain primarily by the Late Cretaceous Claggett Shale, with the overlying Judith River Formation exposed in some higher-elevation areas. The apex of the Bowdoin Dome lies a few miles to the north; this structural dome is a significant hydrocarbon trap and supports an active natural gas field. Surficial sediments underlying the Lake Bowdoin basin are generally described as "alluvium", mapped as a broad east-west band underlying the lake. These deposits are apparently continuous with permeable gravels underlying lower Beaver Creek to the east, which are believed to be glacial in origin.

Hydrologic type. Lake Bowdoin is an area of natural internal drainage augmented and greatly expanded by a complex system of dikes, water control structures and water imports. Under favorable conditions, managed outflow can occur both to the Dry Lake Unit (a satellite basin to the east of Lake Bowdoin) and directly to Beaver Creek. Outflows are possible only during high water levels, however. Discharge to Beaver Creek did not occur for 7 years prior to the 1994 DHES sampling, during which time the Lake Bowdoin system was effectively closed to surface water outflows.

Basin characteristics. The natural catchment of the Lake Bowdoin Basin is comparatively small, consisting mainly of intermittent drainages from the south which are routed to peripheral wetland areas and ultimately to Lake Bowdoin when flows allow. Since most of the inflow is diverted from the Milk River Irrigation Project, the entire upper Milk River above the Dodson diversion is effectively contributing water and solutes to the Lake Bowdoin system. Delineated contributing areas and tabulated acreage figures for the Bowdoin sites thus include the Milk River basin above Dodson. The WET36 sampling site is immediately adjacent to the inlet structure from the Dodson canal; the site of the inflow from Black Coulee (via peripheral wildlife ponds) is also nearby.

Water chemistry. At the time of sampling, the WET36 site was characterized by highly alkaline "oligosaline" sodium sulfate water. Mineral equilibria indicate oversaturation with carbonate phases. Ammonium, phosphorous (total and orthophosphate) and total

organic carbon concentrations all rank toward the mid-range of values shown by sites classified with Lake Bowdoin. The arsenic concentration ranked toward the lower end of the range shown by Great Plains sites; boron, copper and iron concentrations ranked mid-range within the site classification, and other trace element concentrations were below reporting limits.

Chemical history. Since 1978, the U.S. Fish and Wildlife Service has conducted periodic monitoring of limited water quality parameters at a site very near WET36. These data show a wide range in specific conductance and pH. Reported values of specific conductance range over two orders of magnitude (610 to 60,000 microsiemens/cm) and reported pH values range from an apparently anomalous low of 7.5 to a high of 10.6. The specific conductance measured for this sample (6070 microsiemens/cm) was below the simple average for the USFWS data for this site (7582 microsiemens/cm for 131 measurements).

Dissolved oxygen measurements also show a rather wide range, including summertime lows in the 4 to 5 mg/l range. No wintertime data have been collected as part of this monitoring program.

While there is some question about the extreme pH values reported, generally these data show a very wide seasonal and interannual variability at this site, driven by periodic importation of dilute water from the Dodson Canal, followed by periods of evaporative concentration in an essentially closed-basin setting.

The spatial variability shown by the DHES sampling is substantial; near-synoptic sampling of this site and WET38 near the lake outlet showed 30% increase in total dissolved solids from inlet to outlet areas. The mean specific conductance values for U.S. Fish and Wildlife Service measurements from correlative sites show a 43% higher mean for the outlet end of the lake. Generally, the salinity gradient is likely to be steeper during more strongly evaporative conditions.

Sediments. The wide range of reported concentration of solutes in the water column implies that periodic dissolution and re-precipitation of authigenic mineral phases may occur at this site, perhaps with complex effects on aqueous concentrations of nutrients and trace elements. The sample collected from this site showed arsenic, boron and iron concentrations near the low end of the ranges shown for Plains sites. Other trace element concentrations were below detection limits. Arsenic and boron concentrations were below the reported mean soil concentrations for the Western United States.

Lake Bowdoin North Shore

Climatic setting. The net annual precipitation balance for Lake Bowdoin (from the MAPS database) is -28 inches, placing the Bowdoin sites at the more evaporative end of the range shown by sites in this classification. Monthly mean precipitation for the Malta 7NE climatic station shows a broad summer peak with a maximum in May; the Malta climatic station, with a longer period of record but farther from Lake Bowdoin, shows a pronounced June maximum. Annual totals for the Malta 7NE station, shows the years 1988 to 1992 below the average for the period of record. The total for 1993 (the year prior to sampling) exceeded the average for the period of record by about 2.5 inches.

Geologic setting. The natural catchment of Lake Bowdoin is underlain primarily by the Late Cretaceous Claggett Shale, with the overlying Judith River Formation exposed in some higher-elevation areas. The apex of the Bowdoin Dome lies a few miles to the north; this structural dome is a significant hydrocarbon trap and supports an active natural gas field. Surficial sediments underlying the Lake Bowdoin basin are generally described as "alluvium", mapped as a broad east-west band underlying the lake. These deposits are apparently continuous with permeable gravels underlying lower Beaver Creek to the east, which are believed to be glacial in origin.

Hydrologic type. Lake Bowdoin is an area of natural internal drainage augmented and greatly expanded by a complex system of dikes, water control structures and water imports. Under favorable conditions, managed outflow can occur both to the Dry Lake Unit (a satellite basin to the east of Lake Bowdoin) and directly to Beaver Creek. Outflows are possible only during high water levels, however. Discharge to Beaver Creek did not occur for 7 years prior to the 1994 DHES sampling, during which time the Lake Bowdoin system was effectively closed to surface water outflows.

Basin characteristics. The natural catchment of the Lake Bowdoin Basin is comparatively small, consisting mainly of intermittent drainages from the south which are routed to peripheral wetland areas and ultimately to Lake Bowdoin when flows allow. Since most of the inflow is diverted from the Milk River Irrigation Project, the entire upper Milk River above the Dodson diversion is effectively contributing water and solutes to the Lake Bowdoin system. Delineated contributing areas and tabulated acreage figures for the Bowdoin sites thus include the Milk River basin above Dodson.

Water chemistry. Two samples were collected at this site as part of the DHES program, in May and September of 1993. Neither can be compared directly to the inlet and outlet samples, which were collected in May of 1994. No U.S. Fish and Wildlife Service monitoring point corresponds closely with this site. Changes in gross water chemistry over this period were modest. The total

dissolved solids concentration decreased slightly between sampling events. The pH was a full point higher in the September, and the proportional sodium concentration (as measured by the sodium adsorption ratio) was moderately lower. Orthophosphorous and ammonium concentrations were essentially unchanged over this period; the total organic carbon concentration increased by a factor of 5 between the two sample collections. Trace element concentrations were also essentially unchanged, with mid-range concentrations of arsenic and boron and most others below detection limits.

Note, however, that this degree of seasonal stability may not be representative of the usual trends at Bowdoin. USFWS records from monitoring stations at the inlet and outlet ends of the lake show specific conductance increasing by as much as a factor of three, and decreasing by as much as a factor of 4 within a given year in response to evaporation and episodic inflows of dilute water.

Chemical history. See above.

Sediments. The sediment samples collected at this site showed greater differences than did water, probably due to local spatial heterogeneity in sediment characteristics rather than temporal variability. Arsenic concentrations were similar, but boron concentrations differed by more than a factor of three, with the September sample the lower of the two. Copper differed by more than a factor of 2, again with September showing the lower value. Copper, reported at slightly above the detection limit in the May sample, was reported as below detection in September. Selenium showed the opposite pattern. Only the boron concentration of the May sample was above the mean concentration for soils of the western United States, by a factor of only 1.3.

Lake Bowdoin Outlet

Climatic setting. The net annual precipitation balance for Lake Bowdoin (from the MAPS database) is -28 inches, placing the Bowdoin sites at the more evaporative end of the range shown by sites in this classification. Monthly mean precipitation for the Malta 7NE climatic station shows a broad summer peak with a maximum in May; the Malta climatic station, with a longer period of record but farther from Lake Bowdoin, shows a pronounced June maximum. Annual totals for the Malta 7NE station, shows the years 1988 to 1992 below the average for the period of record. The total for 1993 (the year prior to sampling) exceeded the average for the period of record by about 2.5 inches.

Geologic setting. The natural catchment of Lake Bowdoin is underlain primarily by the Late Cretaceous Claggett Shale, with the overlying Judith River Formation exposed in some higher-elevation areas. The apex of the Bowdoin Dome lies a few miles to the north; this structural dome is a significant hydrocarbon trap and supports an active natural gas field. Surficial sediments underlying the Lake Bowdoin basin are generally described as "alluvium", mapped as a broad east-west band underlying the lake. These deposits are apparently continuous with permeable gravels underlying lower Beaver Creek to the east, which are believed to be glacial in origin.

Hydrologic type. Lake Bowdoin is an area of natural internal drainage augmented and greatly expanded by a complex system of dikes, water control structures and water imports. Under favorable conditions, managed outflow can occur both to the Dry Lake Unit (a satellite basin to the east of Lake Bowdoin) and directly to Beaver Creek. Outflows are possible only during high water levels, however. Discharge to Beaver Creek did not occur for 7 years prior to the 1994 DHES sampling, during which time the Lake Bowdoin system was effectively closed to surface water outflows.

Basin characteristics. The natural catchment of the Lake Bowdoin Basin is comparatively small, consisting mainly of intermittent drainages from the south which are routed to peripheral wetland areas and ultimately to Lake Bowdoin when flows allow. Since most of the inflow is diverted from the Milk River Irrigation Project, the entire upper Milk River above the Dodson diversion is effectively contributing water and solutes to the Lake Bowdoin system. Delineated contributing areas and tabulated acreage figures for the Bowdoin sites thus include the Milk River basin above Dodson. The WET38 sampling site is adjacent to the outlet structure conveying water to the Dry Lake Unit.

Water chemistry. At the time of sampling, the WET36 site was characterized by highly alkaline "oligosaline" sodium sulfate water. Mineral equilibria indicate oversaturation with carbonate phases. Ammonium, phosphorous (total and orthophosphate) and total organic carbon concentrations all rank toward the mid-range of

values shown by sites classified with Lake Bowdoin. Phosphorous (total and orthophosphorous concentrations) and total organic concentrations were noticeably higher than at the WET36 site at the lake inlet. The arsenic concentration ranked toward the lower end of the range shown by Great Plains sites; boron, copper and iron concentrations ranked mid-range within the site classification, all somewhat higher than at WET36. Other trace element concentrations were below reporting limits.

Chemical history. Since 1978, the U.S. Fish and Wildlife Service has conducted periodic monitoring of limited water quality parameters at a site on the eastern arm of Lake Bowdoin, less than a mile from WET38. As with the inlet-area station, these data show a wide range in specific conductance, pH and dissolved oxygen. Reported values of specific conductance range from less than 1000 microsiemens/cm to 39000 microsiemens/cm, and reported pH values range from 8.1 to an extremely high 11.0. The specific conductance measured for this sample (7800 microsiemens/cm) was considerably below the simple average for the USFWS data for this site (10871 microsiemens/cm for 151 measurements).

As at WET36, reported dissolved oxygen measurements also show a rather wide range, including summertime lows in the 1 to 2 mg/l range. No wintertime data have been collected as part of this monitoring program.

While there is some question about the extreme pH values reported, generally these data show a very wide seasonal and interannual variability at this site, driven by periodic importation of dilute water from the Dodson Canal, followed by periods of evaporative concentration in an essentially closed-basin setting.

The spatial variability shown by the DHES sampling is significant; near-synoptic sampling of this site and WET36 near the lake inlet showed a 30% increase in total dissolved solids from inlet to outlet areas. The mean specific conductance values for U.S. Fish and Wildlife Service measurements from correlative sites show a 43% higher mean for the outlet end of the lake. Generally, the salinity gradient is likely to be steeper during more strongly evaporative conditions. Nitrogen (nitrate and ammonium) concentrations were indistinguishable between WET38 and WET36. Total and orthophosphorous concentrations, however, increased disproportionately with respect to salinity from inlet to outlet areas (80% and 74% respectively).

Sediments. The wide range of reported concentration of solutes in the water column implies that periodic dissolution and re-precipitation of authigenic mineral phases may occur at this site, perhaps with complex effects on aqueous concentrations of nutrients and trace elements. The sediment sample collected from this site showed generally enriched trace element concentrations in comparison to the other Bowdoin sites. This may reflect heterogeneities in sediment grain size and other characteristics; alternatively, irrigation return flows delivered to the

southeastern lake arm via the Drumbo Unit may carry higher concentrations of some trace elements than do other inflows.

Arsenic, boron, chromium, iron, nickel, vanadium, and zinc concentrations ranked toward the upper end of the ranges shown by sites classified with Lake Bowdoin. The copper concentration ranked mid-range with respect to sites in the same class, and other trace elements were below reporting limits. Boron exceeded soil concentrations for the western United States by a factor of 3 and arsenic by a factor of 1.3; most other concentrations were near or below regional mean soil concentrations.

Lake Mason National Wildlife Refuge

Climatic setting. The net annual precipitation balance (from the MAPS database) is -30 inches, placing Lake Mason at the extreme of the range of evaporative intensity shown by the sampling sites. Mean monthly precipitation for the Roundup climatic station shows a pronounced June maximum. Annual total precipitation in Roundup shows the 3-year running average meeting or exceeding the long-term average since the mid-1980s. Total precipitation in 1992 (the year prior to sampling) was about 1.5 inches above the long-term average, and in 1993 precipitation exceeded the average by about 5 inches.

Geologic setting. The Lake Mason basin is underlain by surficial deposits of inferred lacustrine and paludal origins, apparently of low permeability and up to 40 feet in thickness. The lake lies within a structurally controlled basin situated near the axis of a syncline; in most of the basin, the Lance Formation (a dependable low-yield sandstone aquifer) underlies surficial sediments or is exposed at the surface. Peripheral areas of the basin are underlain by Bearpaw Shale and Judith River Formation; dissected areas of permeable terrace gravels lie elevated along drainage divides.

Hydrologic type. Lake Mason is a natural, structurally controlled, unglaciated basin altered by the construction of a dam and outlet control structure. The lake has surface water inflow and outflow; the record of discharge through the control structure is not known. Recent outflow may be inferred, however, from the dilute water quality at the time of sampling.

Basin characteristics. Lake Mason occupies a low-gradient basin receiving controlled inflow from the Willow Creek drainage and overflow from upgradient intermittent lakes. The catchment to wetland area ratio ranks toward the middle of the range for sites of the unglaciated plains. Mapped stream patterns suggest a shallow ground-water system may influence Lake Mason. Upstream water storage, irrigation diversions and (probably) return flows affect the quantity and timing of the runoff received by the lake. Permeable upland terrace gravels in the Willow Creek drainage may support streamflows with ground-water storage.

Water chemistry. At the time of sampling, Lake Mason water was of an alkaline, "oligosaline" magnesium/sodium-bicarbonate character. Mineral equilibria indicate substantial oversaturation with carbonate phases. Ammonium, phosphorous and total organic carbon concentrations all ranked mid-range for sites in this classification. Arsenic and boron concentrations were toward the lower end of the ranges shown by sites of the unglaciated plains. Lake Mason was among a cluster of 5 sites from the region with much higher chromium concentrations than the rest of the sample set. The copper concentration was also very high, matched or exceeded only by nearby Warhorse National Wildlife Refuge and by western Montana

sites with known mining impacts. The lead concentration reported was also the highest for this class.

Chemical history. No other water chemistry data from Lake Mason are known.

Sediments. Arsenic, copper and iron concentrations rank toward the high end of the ranges shown by sites of the unglaciated plains. Boron, chromium, nickel, vanadium and zinc concentrations ranked low to mid-range. Most other trace elements were below detection limits. Copper and boron concentrations exceeded mean concentrations for soils and other surficial materials of the western United States by factors of about 2; other trace elements were below regional mean soil values.

Lake Thibadeau Northeast

Climatic setting. The net annual precipitation balance for the Lake Thibadeau Northeast site (from the MAPS database) is -26 inches, at the upper end of evaporative intensity for sample sites of the glaciated plains. Mean monthly precipitation for the Havre climatic station shows a pronounced June maximum. Annual precipitation totals for the Havre station show an apparent periodicity with a period of 5 to 7 years. From 1987 to 1990, the three-year running average was below the average for the period of record; from 1991 through 1993, the running average met or exceeded the average for the period of record. In 1993, the year prior to sampling, total precipitation exceeded the average by about 5 inches.

Geologic setting. No satisfactory geologic mapping of this site was discovered in a search of published resources. Small-scale geologic mapping shows the area to be underlain by the Late Cretaceous Bearpaw Shale. The site is within the extent of Pleistocene glaciation, and Bearpaw Shale outcrops in the area are probably underlain by calcareous, poorly permeable till; no description of surficial sediments was discovered, however.

Hydrologic type. The wetland area sampled is an artificial impoundment of an intermittent first-order stream. Contour closure suggests that the site may have been a wetland prior to the construction of the impoundment, though no documentation of the site history is available. The impoundment has an outlet structure, but the frequency and duration of outflow are not known. The dilute water chemistry exhibited at the time of the DHES sampling suggests recent surface water discharge and flushing of the impoundment.

Basin characteristics. The catchment is a low-gradient upland basin with a moderate catchment to wetland area ratio. The depth of the small, elongate basin is unknown but probably does not exceed 10 feet based on topographic considerations. Another impoundment upgradient from the sample site probably influences the duration and timing of inflow to the sample site.

Water chemistry. At the time of sampling, the WET40 site contained highly alkaline, dilute water of calcium/sodium-bicarbonate composition. Mineral equilibria indicate over-saturation with carbonate phases. Ammonium, phosphorous (total and orthophosphorous) and total organic carbon concentrations all rank mid-range with respect to other sample sites in the same classification. The arsenic concentration was moderate for sites of the glaciated plains, and the boron concentration was the lowest for any site in this class. Copper and iron concentrations, on the other hand, ranked near the high end for sites in this class. Lead was present at the detection limit, and most other trace elements were reported below detection.

Chemical history. No other chemical data from this site are known.

Sediments. Extractable concentrations of arsenic were toward the low end of the range shown for sites of the glaciated plains. Most other trace elements with reportable concentrations (boron, copper, chromium, iron, nickel, vanadium and zinc) ranked toward the upper end of their respective ranges. Only boron (by a factor of 2) and zinc (1.2) exceeded the mean soil values for the western United States.

Lakeside Wetland

Climatic setting. The net annual precipitation balance for the Lake Bowdoin area (including the Lakeside wetland) is -28 inches, placing the Bowdoin sites at the more evaporative end of the range shown by sites in this classification. Monthly mean precipitation for the Malta 7NE climatic station shows a broad summer peak with a maximum in May; the Malta climatic station, with a longer period of record but farther from Lake Bowdoin, shows a pronounced June maximum. Annual totals for the Malta 7NE station, shows the years 1988 to 1992 below the average for the period of record. The total for 1993 (the year prior to sampling) exceeded the average for the period of record by about 2.5 inches.

Geologic setting. The natural catchment of the Lake Bowdoin area is underlain primarily by the Late Cretaceous Claggett Shale, with the overlying Judith River Formation exposed in some higher-elevation areas. The apex of the Bowdoin Dome lies a few miles to the north; this structural dome is a significant hydrocarbon trap and supports an active natural gas field. Surficial sediments underlying the Lake Bowdoin basin are generally described as "alluvium", mapped as a broad east-west band underlying the lake. These deposits are apparently continuous with permeable gravels underlying lower Beaver Creek to the east, which are believed to be glacial in origin.

Hydrologic type. The Lakeside wetland is a small internally drained basin altered and augmented by dikes, ditches, inlet and outlet control structures, and transportation and utility corridors. Inflow is diverted directly from the Dodson South Canal. Outflow is controlled by a headgate and ditch delivering water to the Dry Lake Unit and to peripheral ponds nearby.

Basin characteristics. The natural catchment of the Lakeside Wetland is minimal in area, with almost all water in the system imported from the Milk River Irrigation Project. Water management objectives for the Lakeside Unit emphasize maintaining low salinity, requiring that a proportionately high water flux through the basin be maintained. The depth of the basin is not available but is inferred to be only a few feet.

Water chemistry. At the time of sampling, the Lakeside wetland contained dilute (for the region), alkaline water of nonspecific composition; divalent and monovalent cations contributed about equally to the solute load, and CO₂ species and sulfate both contributed significantly to the anion equivalence. The dilute nature of the site reflects the import of Milk River Project water to the site in accordance with the refuge management objectives. Equilibrium calculations indicate oversaturation with carbonate minerals. Ammonium and nitrate concentrations were both below detection limits (unusual for Great Plains sites) and orthophosphorous and total phosphorous concentrations were both near the bottom of the ranges for sample sites outside of the Rocky

Mountains province. The total organic carbon concentration was the lowest for the glaciated plains region and among the five lowest in the data set.

Boron was the only trace element present above reporting limits in the Lakeside site; it's concentration was among the lowest of the Great Plains sites.

Chemical history. The U.S. Fish and Wildlife Service has conducted periodic water quality monitoring at the WET41 site since 1978. Generally, these data demonstrate refuge managers' success in maintaining low salinity in the Lakeside unit. The mean of over 150 specific conductance measurements (707 microsiemens/cm) is about 30% higher than specific conductance measured at the time of the DHES sampling, but only rarely has specific conductance exceeded 1000 microsiemens/cm. The two anomalously high values (9780 and 7500 microsiemens on May 26 and June 11, 1992) appear suspect, and must represent either short-term importation of saline water from Lake Bowdoin or, more probably, erroneous measurements. The single anomalously low value (50 microsiemens/cm on April 17, 1979) is also probably an erroneous measurement. Reported pH values range from 8.2 to 11.2, and dissolved oxygen ranged from very high concentrations in excess of 16 mg/l down to the 5 to 6 mg/l range. No wintertime measurements are included in the USFWS monitoring.

Sediments. Arsenic, boron and zinc concentrations rank toward the low end of the ranges shown for Great Plains sampling sites. The iron concentration ranks mid-range among sites in this class, and the copper concentration ranks toward the top of the range shown by the glaciated Great Plains sites. None exceeded the mean values for soils and other surficial materials of the western United States.

Lame Steer National Wildlife Refuge

Climatic setting. The net annual precipitation balance for Lame Steer NWR (from the MAPS database) is -23 inches, toward the less evaporative end of the range shown for sample sites of the unglaciated plains. Mean monthly precipitation for the Wibaux 2E climatic station shows a broad summertime peak with a June maximum. Annual total precipitation for the Wibaux 2E site shows an apparent periodicity with a 5 to 7 year cycle shown by the 3-year running average. Annual totals were below the mean for the period of record during most of the 1980s. Data for the two years prior to sampling were not retrieved for this site.

Geologic setting. The Lame Steer site and the contributing drainage basin are underlain by the Tongue River Member of the early Tertiary Fort Union Formation, made up of sandstone, siltstone, mudstone and coal. Surficial deposits are inferred to be local in origin and distribution, and to reflect the lithologies composing the Fort Union Formation.

Hydrologic type. The Lame Steer wetland is an artificial impoundment of an intermittent second(?) order stream. The reservoir has an outlet structure and surface outflow; the frequency and duration of surface outflow are unknown, however.

Basin characteristics. The Lame Steer impoundment has one of the higher catchment to wetland area ratios among sample sites of the unglaciated plains. Sandstone aquifers of the Fort Union Formation (and possibly clinker) are inferred to provide shallow ground-water storage within the Lame Steer catchment. The water depth is unknown but is inferred from the surrounding topography to be probably no more than 10 feet.

Water chemistry. At the time of sampling, Lame Steer Reservoir contained moderately alkaline, "oligosaline" sodium-sulfate water. Mineral equilibria indicate oversaturation with carbonate species. Ammonium and nitrate concentrations were both below detection limits; phosphorous concentrations (total and orthophosphate) and the total organic carbon concentration also ranked toward the lower end of the range shown for Great Plains sites. Arsenic, boron and iron concentrations ranked relatively low in the ranges shown for Great Plains sites. At slightly above the reporting limit, the lead concentration ranked high among similar sites. Other trace element concentrations were reported to be below reporting limits.

Chemical history. No previous water chemistry data from this site are known.

Sediments. Arsenic, boron, copper, iron, nickel, vanadium, and zinc all rank toward the middle of the ranges shown by sites of this classification, while other trace element concentrations were mainly below reporting limits. Of the reported concentrations, only boron exceeds the mean soil concentration for the western

United States (by a factor of 1.8).

Lavina DOT Mitigation Wetland

Climatic setting. The net annual precipitation balance for the Lavina site (from the MAPS database) is -29 inches, placing WET43 near the more strongly evaporative extreme of the range shown by the sample sites. Mean monthly precipitation for the Barber climatic station shows a June maximum. The 3-year running average of annual precipitation for the Barber station remained below often well below) the long-term average throughout the 1984-1992 period. Annual precipitation in 1993 (the year prior to sampling) exceeded the long-term average by 4 inches.

Geologic setting. The WET43 site is underlain by alluvium of the Musselshell River and of the unnamed northern tributary draining to the wetland site. The character of the alluvium in the immediate vicinity of the wetland is undescribed; in the general vicinity, the Musselshell alluvium is permeable enough to support wells of low to moderate yield. The Judith River Formation underlies surficial deposits at the wetland site; higher-elevation areas within the northern tributary basin are underlain by Bearpaw Shale.

Hydrologic type. WET34 is a modified site, apparently receiving inflow from the unnamed northern tributary and (probably) from the groundwater system of the Musselshell River alluvium. The wetland does not appear to have surface water outflow under the sampled conditions.

Basin characteristics. The contributing catchment for this small site is not well defined. If the catchment is taken to be the northern tributary drainage, the catchment to wetland area ratio ranks mid-range with respect to other sample sites of the unglaciated plains. However, the Musselshell River alluvium (interacting with the Musselshell River throughout the upper river basin) may provide ground-water inflow to the site. The U.S. Highway 12 corridor and excavation for wetland enhancement affect local site hydrology.

Water chemistry. The WET43 site exhibits moderately alkaline, "oligosaline" sodium-sulfate water chemistry. Mineral equilibria indicate oversaturation with carbonate phases. Ammonium and nitrate concentrations were below reporting limits at the time of sampling; phosphorous (total and orthophosphate) and total organic carbon concentrations are low with respect to sites in the same classification.

Boron and iron concentrations were reported at the lower end of the ranges for Great Plains sample sites; most other trace elements were below reporting limits.

Chemical history. No other chemical data for this wetland are known.

Sediments. Relatively recent wetland mitigation activities may have disturbed sediments at the WET43 site. Extractable trace element concentrations are generally low; arsenic, boron, iron, vanadium and zinc concentrations were all at or near the lower end of the ranges shown for sample sites in this classification. Other trace element concentrations were below reporting limits. None exceeded mean soil concentrations for the western United States.

Lebeau Creek South

Climatic setting. The net annual precipitation balance (from the MAPS database) is -5 inches, near the middle of the range of evaporative intensity shown by Rocky Mountain sample sites. Mean monthly precipitation for the Olney climatic station shows a bimodal distribution, with a pronounced June peak and a broad wintertime (November to January) peak. (Much of the catchment contributing runoff to this site is 1000-2000 higher than the Olney gauge, so precipitation records serve only as a general indication of recent precipitation history.) Annual totals for the Olney station are fragmentary; regionally, annual precipitation was above average in 1993 (the year prior to sampling) and below average in 1994.

Geologic setting. The WET44 site is along the margins of the glacially scoured Stillwater Valley and is presumed to be underlain by sediments of glacial origin. No local description of the character of these sediments is available, however. Surficial sediments in the contributing catchment are underlain by formations of the Proterozoic-aged Belt series, including large areas of the dominantly calcareous and dolomitic Helena Formation. Numerous northwest-trending normal faults (structural elements of the Rocky Mountain Trench) cross the general area.

Hydrologic type. The WET44 site occurs along a mapped tributary to Lebeau Creek and has surface water inlet and outlet channels which are mapped as intermittent; discharge rates and duration are not known for this stream. Forest road construction may contribute to the wetland by artificially impounding the outlet stream.

Basin characteristics. The Lebeau Creek site has a high catchment to wetland area ratio in comparison to other Rocky Mountain sites. In conjunction with the moist climate and steep slopes, this characteristic implies a relatively rapid hydrologic flux through the wetland.

Water chemistry. Water in the Lebeau wetland is dilute, mildly alkaline and calcium-bicarbonate in character. Mineral equilibria indicate near-equilibrium with calcite and aragonite and only slight oversaturation with dolomite. Ammonium and nitrate concentrations were below reporting limits; phosphorous (total and orthophosphorous) and total organic carbon concentrations were toward the lower end of the ranges shown by Rocky Mountain sites.

The recoverable iron concentration was near the lower end of the range shown for sites in this class, and copper was reported at the detection limit. Other trace elements were below reporting limits.

Chemical history. No other chemical data are known from this site.

Sediments. The extractable selenium concentration reported for this site is the highest for any of the Rocky Mountain sample

sites, and among the highest in the data set. The reported zinc concentration is among the highest for sites not known to be impacted by mine wastes. WET44 is also one of the few sites not known to be impacted by mining waste where extractable lead was reported. The selenium concentration exceeded the mean soil value for the western United States by a factor of 4; the zinc concentration exceeded the regional mean by a small factor. Other trace element concentrations were either low with respect to sites in this class, or below reporting limits.

Lee Metcalf National Wildlife Refuge

Climatic setting. The net annual precipitation balance for the Lee Metcalf NWR (from the MAPS database) is -24 inches, near the more strongly evaporative extreme for sites in the intermontane valleys and in western Montana generally. Mean monthly precipitation for the Western Agricultural Experiment Station (near Stevensville) shows a relatively broad distribution with a maximum in May. The 3-year moving average of annual precipitation totals for the Western Ag Station was below the long-term average from 1985 to 1992. In 1993 (the year prior to sampling) precipitation exceeded the long-term average by about 2.5 inches. Data for 1994 (the year of sampling) were not retrieved; regionally, 1994 totals were below average.

Geologic setting. The Lee Metcalf Refuge is underlain by permeable alluvium of the Recent Bitterroot River floodplain. Alluvial terraces of the Bitterroot River and floodplain and fan deposits of tributary streams border the refuge. Glaciofluvial gravels and fine-grained Tertiary-aged sediments underlie the Holocene alluvium at depth and form elevated benches to the east. Shallow water table depths and ground-water discharge areas occur beneath and around the refuge, contributing some of the water budget of the wetland complex.

Hydrologic type. The Lee Metcalf site is an artificial impoundment holding both natural ground-water discharge and imported water from the Burnt Fork and Threemile Creek drainage. The impounded wetland sampled at site WET45 has surface water outflow and probably also has ground-water outflow under at least some conditions.

Basin characteristics. The natural surface catchment of the WET45 wetland is relatively small. The natural surface catchment is little importance to the site's water balance, however, since most water is contributed either by ground water in probable connection with the Bitterroot River, or by surface water imported from tributary drainages. Water depths are not available, but are probably quite shallow.

Water chemistry. At the time of sampling, the Lee Metcalf wetland contained dilute water of mixed cation-bicarbonate composition and high (biologically influenced) pH. Equilibrium calculations indicate oversaturation with carbonate minerals under the high pH conditions measured. Ammonium, nitrate and orthophosphate concentrations were below reporting limits, and total phosphorous and total organic carbon concentrations were near the lower end of the ranges shown for sites in any class.

Arsenic and iron (both reported at their detection limits) and copper concentrations were at the lower end of the ranges shown by sample sites within this class. Most other trace element concentrations were below reporting limits.

Chemical history. No other chemical data from this site are known. Water quality concerns at the refuge have included sediment and herbicides in conveyances linked to refuge water supplies.

Sediments. Extractable arsenic, boron, iron and zinc were reported at concentrations near or at the lower end of the ranges shown by the entire data set. Most other trace elements were below reporting limits. None exceeded the mean values for soils and other surficial materials of the western United States.

Long Lake

Climatic setting. The net annual precipitation balance for the Long Lake site (from the MAPS database) is -26 inches, placing the site near the mid-range of evaporative intensity for hydrologically similar sites. Monthly average precipitation for the Sunburst 8E climatic station show a broad summer peak with a maximum in June. Since the mid-1970's, the 3-year running average of annual precipitation for the Sunburst station was mainly at or above the mean for the period of record. Data for 1993 and 1994 were not recovered for this station; regionally, 1993 totals were well above average and 1994 totals were below average.

Geologic setting. The Willshaw Flats basin is underlain by lacustrine and paludal sediments (including chemical precipitates) with calcareous glacial till forming the immediately adjacent upland slopes. The Willshaw Flats topographic depression has been interpreted as a south flowing ice-marginal drainage during late Pleistocene time. If this interpretation is correct, it is possible that glaciofluvial sediments underlie Holocene lacustrine deposits beneath the wetland complex.

Surficial deposits are underlain by shale and sandstone of the Colorado Group.

Hydrologic type. Long Lake is a depression (glacial drainage?) lacking surface outflow. (Although it lies within the limits of Pleistocene glaciation and is developed in glacial deposits, the basin is not thought to be the direct result of the action of ice, as are most sites with which Long Lake is classified.) The extent of flooded area in Willshaw Flats is unusually transient with respect to the set of sample sites. Surface water outflow would require major changes in the Willshaw Flats water budget.

Basin Characteristics. The Willshaw Flats basin is an extensive complex of playa surface and vegetated wetland receiving runoff from upland areas to the east. Topographic gradients within the basin are very low and observed water depths were on the order of 1 foot near the center of the sampled wetland; raising the stage the 10 feet or more needed to allow surface outflow would require storing a very large volume of water within the basin. No abandoned shorelines which might correlate to outflow-controlled stage were observed. It seems probable that the basin has been internally drained throughout the Holocene. Water storage in Beaupre Coulee, the major drainage contributing runoff to the Willshaw Flats Basin, may have reduced the runoff received by the wetland complex during recent historic times. Wetland extent and shoreline position are unusually transient.

Water chemistry. At the time of sampling, Long Lake contained mixed-cation/sulfate "oligosaline" water with specific conductance of 4840 microsiemens/cm. Equilibrium calculations indicate moderate supersaturation with carbonate species and undersaturation

with gypsum.

Water column zinc and copper concentrations were among the higher values for hydrologically similar sites. Other trace element concentrations were below detection limits or were near mid range for hydrologically similar sites.

Orthophosphate and total phosphorous concentrations were the second highest among the entire sample set. As with other very high phosphorous sites, almost all of the total phosphorous occurred as orthophosphate. Nitrate was reported at the detection limit of .01 mg/l and ammonium was found to be below detection limits. The total organic carbon concentration was near the upper end of the range for all sample sites.

Chemical history. No chemical data prior to the DHES sampling are known for the Long Lake site. Measurements in August of 1994, two months after sample collection, showed specific conductance of 20500 microsiemens/cm. This represented a fourfold seasonal increase in two months. With this concentration increase, Long Lake probably reached saturation with gypsum and other mineral phases. Water quality is inferred to be typically very transient due to shallow basin geometry, high effective evaporation rates and the lack of surface outflow.

Sediments. Concentrations of nickel, chromium, vanadium, selenium and zinc were at or near the upper end of the range for sample sites of this hydrologic type. Concentrations of zinc, nickel, selenium and arsenic exceed mean soil values for the western United States. Very high iron concentrations, in combination with obviously reduced sediment conditions, suggest possible iron sulfide (pyrite) formation.

Mallard Pond

Climatic setting. The net annual precipitation balance for Mallard Pond derived from the MAPS database is -23 inches, toward the less evaporative end for sites in this class. Based on analyses of evaporation pan data, this is a considerable underestimate Mallard Pond's water deficit, and points out the need to view the MAPS estimates only as relative indicators of net site precipitation. Mean monthly precipitation for the Medicine Lake climatic station shows a pronounced June maximum. Annual totals for this station show apparent periodicity with a 5 to 7 year cycle. Throughout the 1980s, the 3-year running average remained below (often well below) the long-term average, recovering in the early 1990s. In 1993 (the year before sampling) precipitation exceeded the long-term average by more than 1 inch.

Geologic setting. Mallard Pond occupies an ice-block depression (kettle) in the sequence of pitted late Pleistocene outwash sand and gravel forming the Clear Lake aquifer. Glacial sediments are underlain at depth by the early Tertiary Fort Union Formation.

Hydrologic type. Mallard Pond is a glacial depression lacking significant surface water inflow but possessing surface water (and probably ground-water) outflow. Inflow to the pond is primarily discharging ground water from the Clear Lake aquifer.

Basin characteristics. Mallard Pond has only a minimal surface catchment; the catchment to wetland area ratio ranks toward the lower end of the range shown by sample sites of the Great Plains. The pond is surrounded on three sides by steep kettle walls; on the low-gradient west side, the pond drains by discontinuous(?) channels and ground-water flow toward the Lake Creek channel. The depth of the pond is unknown but believed to be shallow. The WET47 site is on the upgradient side of Mallard Pond with respect to the regional Clear Lake aquifer flow system; important spatial water quality gradients can exist within this small pond, as shown by previous sampling (see below).

Water chemistry. At the time of sampling, Mallard Pond contained "oligosaline" sodium-sulfate water of moderately alkaline pH and depressed dissolved oxygen content. Substantial calcium remained in solution and mineral equilibria indicated slight oversaturation with calcite and aragonite. The sample was collected in an area of probable ground-water discharge and is interpreted to have been out of equilibrium with surface conditions (see below). The ammonium concentration was the highest of sites in this classification, and among the highest in the sample set; significant nitrate (among the four highest sample sites) was also present. Phosphorous (total and orthophosphorous) and total organic carbon concentrations ranked mid-range among sites of the glaciated Great Plains, but toward the upper end of the ranges shown by sites possessing surface water outlets.

Arsenic, boron and iron concentrations ranked mid-range among sites classified with WET47; most other trace element concentrations were below reporting limits.

Chemical history. The previous known chemical sampling of Mallard Pond (conducted in August of 1990) included specific conductance measurements from three points on the pond perimeter, including one site very near WET47, and analytical water chemistry for a single sample collected on the opposite (western) shoreline. The specific conductance measurements demonstrated a substantial cross-pond gradient in salinity; specific conductance at the two sites on the western shoreline was higher than that near WET47 (measured 3 days earlier) by a factor of 1.75. The WET47 sample was also higher in specific conductance than the 1990 measurement collected nearby, by a factor of 1.4.

Although moderately higher in total dissolved solids, the 1990 sample from the western shore was substantially lower in calcium concentration than was the 1994 DHES sample from WET47. The field pH of the 1990 sample was reported as 9.48, very similar to the laboratory value reported for the WET47 sample. Taken together with the depressed mid-day dissolved oxygen concentration for the WET47 sample, it can be inferred that the WET47 sample was collected from an area of ground-water discharge where CO₂, dissolved oxygen and dissolved carbonate phases had not yet equilibrated with the surface environment. The 1990 data show that this adjustment, along with evaporative concentration and increasing specific conductance, occurs during circulation of lake water from the upgradient (eastern, WET47) shoreline to the downgradient (western) side of the lake.

Sediments. As with Brush Lake and other relatively dilute ground-water fed lakes in the area, the water chemistry data described above imply loss of calcium (as calcium carbonate) from the water column as ground-water enters the lake environment. The high calcium concentration reported in the sediment analysis presumably reflects active marl formation as part of Mallard Pond's sedimentary regime.

Extractable arsenic, boron, iron and zinc concentrations rank low to mid-range with respect to similarly classified sites. None exceed the mean soil values for the western United States.

Mary's Frog Pond Botanical Area

Climatic setting. The net annual precipitation balance for Mary's Frog Pond (from the MAPS database) is 20 inches, placing this sampling site among the five moist high-elevation sites in the data set. None of the NOAA climatic stations provide data particularly applicable to the Mary's Frog Pond site; Lolo Hot Springs, the nearest climatic station, is at a considerable lower elevation and has a sporadic recent record. Mean monthly precipitation at the Lolo Hot Springs Station shows a bimodal distribution, with a January maximum and a secondary June peak. Regionally, precipitation totals in 1993 were above average and in 1994 (the year of the DHES sampling) were below average.

Geologic setting. Mary's Frog Pond is underlain by the Ravalli Group of the Proterozoic-aged Belt series. The intrusive contact of the Idaho Batholith is very nearby, however, and mineralization presumably related to hydrothermal intrusive processes occurs in the immediate vicinity. Surficial deposits in the area are apparently undescribed, and the origins of the pond basin are unclear from the available information. One source describes the pond as a "glacial scour", but there is no supporting documentation given for this interpretation, and the drainage in which the pond lies does not have obvious glacial landforms.

Hydrologic type. Mary's Frog Pond is a small, internally drained depression of uncertain origin, which lacks both surface water inflow and outflow at the water levels observed during sampling.

Basin characteristic. Mary's Frog Pond has a small, steep surface water catchment and a catchment to wetland area ratio which ranks low among Rocky Mountain sites. The depth of the pond is unknown. Given the setting in an area of high net precipitation, the pond is inferred to discharge either via ground-water or by unmapped surface-water outflow (or both). Surface features within the wetland catchment include a portion of an access road to the abandoned Ward Lode mine.

Water chemistry. Mary's Frog Pond contains extremely dilute, somewhat acidic water with sodium and potassium in excess of calcium and magnesium. The anion distribution is uncertain due to the dilute nature of the water. Mineral equilibria indicate highly undersaturated conditions with respect to carbonate phases; saturation indices are not quantitatively meaningful, however, due to the large charge balance error in the analysis.

Nutrient concentrations are very low; ammonium and nitrate concentrations were below reporting limits, and orthophosphate and total phosphorous concentrations were at or near the lower end of the ranges for the entire sample set. The total organic carbon concentration was also relatively low.

With the exception of aluminum, iron, and silica (all reported at

concentrations at or near the lower end of the ranges shown for the entire sample set), water column trace element concentrations were below reporting limits.

Chemical history. There is a single partial chemical analysis for Mary's Frog Pond known prior to the DHES sampling. This sample, collected in June of 1987, was slightly more dilute than the DHES sample, and had grossly similar major-ion chemistry. Generally, seasonal and interannual variation at this site is probably minimal.

Sediments. Extractable arsenic, copper, iron and zinc concentrations rank low or mid-range for sample sites within this classification. Mary's Frog Pond is among the handful of sampling sites with reported lead concentrations; most other trace element concentrations were below reporting limits. The lead concentration exceeded the mean value for soils of the western U.S. by a factor of 1.4.

Medicine Lake

Climatic setting. The net annual precipitation balance for Medicine Lake derived from the MAPS database is -24 inches, toward middle of the range of evaporative intensity for sites in this class. Based on analyses of evaporation pan data, this is a considerable underestimate Medicine Lake's water deficit, and points out the need to view the MAPS estimates only as relative indicators of net site precipitation. Mean monthly precipitation for the Medicine Lake climatic station shows a pronounced June maximum. Annual totals for this station show apparent periodicity with a 5 to 7 year cycle. Throughout the 1980s, the 3-year running average remained below (often well below) the long-term average, recovering in the early 1990s. In 1993 (the year before sampling) precipitation exceeded the long-term average by more than 1 inch.

Geologic setting. Medicine Lake occupies a large depression in the sequence of late Pleistocene outwash sand and gravel forming the Clear Lake aquifer. The composite thickness of the outwash gravels is greater in the Gaffney-Medicine Lake vicinity than elsewhere along the Clear Lake outwash channel. Preglacial terrace gravel aquifers are apparently incised by outwash sediments in the vicinity of Medicine Lake, creating hydrologic linkages between stratigraphically distinct aquifers and surface water bodies. Glacial and sediments and preglacial alluvium are underlain at depth by the early Tertiary Fort Union Formation.

Hydrologic type. Medicine Lake is a natural ground-water discharge area for the Clear Lake Aquifer which has been modified to stabilize water levels and to accommodate water imports diverted from Muddy Creek. Additional inflow is supplied by Lake Creek, which delivers limited runoff and ground-water discharge to Medicine Lake and other basins. Outflow from Medicine Lake to Muddy Creek is also managed by control structures. Often the full water right for the Big Muddy diversion cannot be exercised, however, and the lake may go several consecutive years without spilling surface water.

Basin characteristics. The water budget of Medicine Lake is dominated by ground-water inflow and by extra-basin imports from Big Muddy Creek; neither is closely linked to the natural surface water catchment of the lake. Regionally, evaporative losses from Medicine Lake (and other lakes) are the predominant outflow component of the Clear Lake Aquifer's water budget and are an important influence on ground-water gradients and ground-water flux. Imports of Big Muddy Creek water to Medicine Lake are believed to have a corollary effect on the aquifer, stabilizing ground-water levels in the vicinity of the lake.

The U.S. Fish and Wildlife Service estimates the capacity of Medicine Lake at "management elevation" at about 88300 acre-feet, with an average lake depth of about 10 feet. From 1988 to 1993 year-ending lake volumes ranged from 66% to 75% of this management

capacity; at the beginning of 1994 (the year of the DHES sampling) the lake was at approximately 69% of "management capacity". This represented a slight gain in storage over the previous year. In midsummer of 1993, runoff in Big Muddy Creek allowed for diversion of several hundred cfs, raising the lake level almost two feet in a matter of a few days. This kind of rapid episodic fill and lake level rise, followed by periods of progressive water-level decline, is probably characteristic of the management of Medicine Lake.

Water chemistry. At the time of sampling, the WET49 site exhibited "oligosaline" sodium-sulfate water with near-neutral pH and low dissolved oxygen concentration. Substantial calcium and carbonate remained in solution, and mineral equilibria indicate moderate oversaturation with respect to carbonate phases. The ammonium and total phosphorous concentrations were high in comparison to the sample sites in this class; orthophosphate and total organic carbon concentrations ranked mid-range within the site classification.

Concentrations of arsenic, boron and iron ranked low among sites of this class; most other trace element concentrations were below reporting limits.

Chemical history. Occasional measurements of field water quality parameters are available since 1984, with quantitative water chemistry from one Medicine Lake site in 1990. Beginning in 1994, the U.S. Fish and Wildlife Service has measured limited field parameters (specific conductance, dissolved oxygen and temperature) on an approximately monthly basis from five sites in Medicine Lake, including one relatively near the DHES site WET49. These data demonstrate substantial spatial gradients in salinity within the lake, as well as temporal variability in water quality within regions of the lake basin.

In September of 1984, measurements of specific conductance at ten different points along the lake shoreline yielded a mean of 2060 microsiemens/cm, with a minimum of 1590 and a maximum of 3053 microsiemens/cm. Eight specific conductance measurements in August of 1990 ranged from 650 (at the Muddy Creek diversion inflow?) to 4760 microsiemens/cm, with a mean of 4034. A DHES survey of 4 shoreline sites in May of 1993 yielded a mean of 5555 microsiemens/cm and a range from 3460 to 6410 microsiemens/cm. In all cases where sites near WET49 were measured they were the least saline within the lake at that time, with the exception of the August 1990 low reading of 650 microsiemens/cm, which may have been collected from the Muddy Creek inlet itself rather than from the lake. This is consistent with the presence of ground-water inflow to Lake Creek and to the eastern (upgradient) end of Medicine Lake; surface runoff from the Lake Creek catchment, when it occurs, will further dilute water at the WET49 site relative to other parts of the lake basin.

The pH and dissolved oxygen concentrations are both relatively low in the WET49 sample. The 1990 analysis, conducted on a sample

collected from the southern side of the lake, had a field pH in excess of 9.0, as did all four sites in the 1993 DHES survey of Medicine Lake field chemistry. The 1990 sample, with a substantially higher dissolved solids concentration, had a lower absolute concentration of calcium than the WET49 sample, suggesting the process of atmospheric equilibration and consequent calcium carbonate precipitation characteristic of many lakes linked to the Clear Lake aquifer is ongoing in Medicine Lake. The WET49 sample, collected at the eastern (upgradient) end of the lake, appears to have consisted largely of ground-water discharge not yet equilibrated with the surface environment. Samples collected from the WET49 site should not be expected to represent the chemical characteristics of the main Medicine Lake basin.

Historically, Medicine Lake is reported to have been essentially dewatered during the extended drought of the 1930's, stimulating the construction of the diversions and control structures now used for water management. Under naturally fluctuating conditions, water chemistry, as well as shoreline position and water depth, was probably more transient than now, and average salinity likely was higher prior to the import of Big Muddy Creek runoff.

Sediments. Arsenic and boron concentrations in the WET49 sample were near the upper end of the ranges shown for this classification, and the selenium concentration reported for this site was the highest in it's class. Iron, nickel, vanadium and zinc concentrations ranked mid-range within the site classification; most other trace elements occurred at concentrations below their reporting limits.

McKillop Creek

Climatic setting. The net annual precipitation balance for the McKillop Creek site (from the MAPS database) is -3 inches, ranking the site mid-range in moisture regime among Rocky Mountain sites. Mean monthly precipitation for the Libby Ranger Station climatic station shows a bimodal distribution, with a wintertime (November-January) maximum and a secondary June peak. Annual total precipitation for the Libby RS station shows the 3-year running average at or above the long-term annual average from 1983 through 1993. The annual total in 1993 (the year prior to sampling) was equal to the long-term average.

Geologic setting. The McKillop Creek wetland is underlain by glacial(?) deposits of undescribed character. Bedrock formations underlying the site and the contributing drainage basin belong to the Proterozoic-aged Belt series, including the dominantly calcareous and dolomitic Wallace Formation. The wetland site closely overlies the intersection of two mapped normal faults, one trending northwest along lower McKillop Creek and its unnamed south fork, and the other trending northeast across the two forks of McKillop Creek. The McKillop Creek wetland's peculiar water chemistry (see below) suggests that the wetland may receive a component of inflow from deeply circulating bedrock ground-water.

Hydrologic type. The McKillop Creek wetland occupies one of a pair of basins of uncertain (glacial?) origin, lacking a surface water outlet at the observed water levels and possessing a surface water inlet stream mapped as intermittent in flow. The relatively moist setting and dilute water chemistry imply outflow from the site either by ground-water recharge or by unmapped surface water outflow.

Basin characteristics. The McKillop Creek wetland has a notably steep catchment and a relatively large catchment area to wetland area ratio, implying rapid hydrologic flux through the wetland. The northeastward orientation of the catchment may favor retention of winter snowpack. The depth of the wetland water body is unknown but probably quite shallow. Bedrock structural controls may influence basin topography and wetland water chemistry.

Water chemistry. The McKillop Creek wetland exhibits a mildly acidic, dilute sodium/potassium-bicarbonate/chloride composition which is unique among the sample sites. The high ratios of sodium to total cations and chloride to total anions suggests either contamination with sodium chloride road salt (an uncommon deicing salt) or inflow from dilute but deeply circulating ground water. The latter explanation is favored on the basis of other chemical characteristics described below. Mineral equilibria indicate substantial undersaturation with respect to carbonate phases despite the presence of calcareous and dolomitic rocks within the basin.

The ammonium concentration in this sample is uniquely high for sample sites in the Rocky Mountains, exceeding all other sample sites by an order of magnitude. The orthophosphate concentration was also the highest for Rocky Mountain sites, though not disjunct from the range shown by other sites as was the ammonium concentration. The total organic carbon concentration ranked mid-range among Rocky Mountain sites.

The boron concentration was the highest shown by Rocky Mountain sites, most of which did not contain the element in reportable concentrations. Arsenic, iron and copper were reported at concentrations ranking mid-range within the site classification. Most other trace elements occurred at concentrations below the reporting limits.

Chemical history. No other chemical data from this site are known.

Sediments. In comparison to other dilute Rocky Mountain sites, the McKillop Creek wetland appears to display a diverse array of detectable trace elements. Arsenic, boron, copper, nickel, selenium, vanadium and zinc were all reported at concentrations ranking the site mid-range among similarly classified sample wetlands. Only selenium (by a factor of 1.7) and zinc (by a small amount) exceeded the mean concentrations for soils and other surficial materials in the Western United States.

Mill-Willow Silver Bow wetland.

Climatic setting. The net annual precipitation balance for the Mill-Willow site (from the MAPS database) is -22 inches, placing the site toward the more evaporative end of the range shown by sample sites in the western intermontane valleys. Mean monthly precipitation for the Anaconda climatic station shows a broad summertime peak. Annual precipitation totals for the Anaconda station show the 3-year running average falling below the long-term average from 1987 through 1992, the year of the DHES sampling. The 1992 total was about 1 inch below the long-term average. Water supply at this site is probably more dependent on the condition of mountain snowpack than on the low-elevation precipitation measured at the Anaconda station.

Geologic setting. The WET51 site is underlain by Quaternary-aged unconsolidated alluvial deposits, probably to a thickness of a few tens of feet. Tertiary-aged valley-fill sediments underlie the Quaternary alluvium; these sediments may be near their local maximum in thickness beneath the sampling site, thinning rapidly to the east and west. Recent alluvial sediments and shallow ground-water in the Mill-Willow-Silver Bow area are pervasively contaminated with mineral processing wastes.

Hydrologic type. The WET51 site is in a riparian wetland in an area of apparent local ground-water discharge, with perennial surface water inflow and outflow and close surface water-ground water linkages. The site has been modified to some degree by ditching, with unknown effects on wetland hydrology.

Basin characteristics. The mountain basin of Willow Creek provides a relatively large, high-elevation catchment for the WET51 site; the catchment to wetland area ratio ranks toward the upper end of the range shown by sites in this classification. Willow Creek and other local streams provide recharge to shallow ground-water systems; ground-water discharge occurs along gaining stream reaches and in wetland areas such as that sampled at WET51. Historic mine wastes are broadly distributed in the Silver Bow and Mill Creek drainages. Contamination with mineral processing waste is also suspected to have caused soil and ground-water contamination in the Willow Creek drainage. Low stream gradients, overbank sedimentation and probable channel migration in the vicinity of the WET51 site suggest that the sample site (located near the present Willow Creek channel) may be underlain by contaminated sediments derived from Silver Bow Creek and Mill Creek, as well as Willow Creek sediments.

Water chemistry. The WET51 site is characterized by dilute calcium-bicarbonate water of near-neutral pH. The sulfate concentration appears to be proportionately higher than for many other dilute sample sites in western Montana. Mineral equilibria indicate approximate saturation with carbonate phases. The nitrate concentration ranked mid-range for sample sites of this class;

ammonium was below reporting limits. The orthophosphate concentration was toward the lower end of the range shown by sites in this classification. Total phosphorous and total organic carbon analyses were not conducted on this sample.

Copper and zinc concentrations ranked mid-range among sites of the intermontane valleys, exceeded mainly at other mine-impacted sites. Iron and aluminum concentrations were not analyzed for this sample, and other trace element concentrations were below reporting limits.

Chemical history. No other comparable chemical analyses are known for this site. Generally, increased concentrations of toxic metals have been observed at times of runoff and high flows in the Silver Bow/Mill Creek system as sediment deposits contaminated with mineral processing waste are remobilized.

Sediments. Exceptionally high concentrations of extractable arsenic, copper, lead and zinc are matched only by other sites with known mine or mineral processing impacts. Iron, chromium, nickel and vanadium concentrations are also relatively high in comparison to similarly classified sites. Arsenic, copper, lead and zinc concentrations far exceed mean soil concentrations for the western United States; other trace element concentrations are below their respective mean soil values.

Ninepipe Reservoir Outlet

Climatic setting. The net annual precipitation balance for the Ninepipe Reservoir area (from the MAPS database) is -18 inches, placing this site toward the middle of the range of evaporative intensity shown by sample sites of the intermontane valleys. Mean monthly precipitation for the St. Ignatius climatic station shows relatively even distribution with a maximum in May and June. Total precipitation for the St. Ignatius station shows the three-year running average remaining near or above the long-term average from 1980 through 1993. Water supply in Ninepipe Reservoir, however, is largely dependent on the storage and controlled release of runoff from mountain snowpack. Hence the low-elevation St. Ignatius station cannot be expected to closely reflect hydrologic conditions in the reservoir or associated wetland areas.

Geologic setting. The Mission Valley generally is underlain by glacial sediments deposited by the southward advance of the late Pleistocene lobe which occupied the Flathead Lake basin. Sediments in the Ninepipe area include till of different textures, glaciolacustrine sediments and outwash in complex stratigraphic sequences. Regional source areas for glacial sediment are mainly underlain by metasedimentary rocks of the Proterozoic-aged Belt series, including calcareous and dolomitic lithologies. Generally the kettle-pitted surface underlying the Ninepipe National Wildlife Refuge is composed of till of relatively low permeability. Permeable aquifer gravels within the upper 200 feet of the glacial sequence support high-yield wells nearby.

Hydrologic type. The WET52 site is within a ponded riparian area fed by the regulated outflow from Ninepipe Reservoir. Inflow to the reservoir is largely imported water from streams draining the Mission Mountains to the east, routed to Ninepipe via other reservoirs and an extensive ditch system.

Basin characteristics. The natural catchment of Ninepipe Reservoir includes a relatively small area along the Mission Mountain front. As managed, the catchment includes upper Post Creek, draining the highest peaks of the Mission Mountains.

Water chemistry. The WET52 sample shows dilute calcium-bicarbonate composition with near-neutral pH. Mineral equilibria indicate slight undersaturation with carbonate phases. Ammonium, phosphorous and total organic carbon concentrations rank mid-range among similarly classified sampling sites. Chromium was reported at the detection limit (one of only 3 western samples with reportable concentrations), and the iron concentration ranked toward the upper end of the range shown by this class of sampling site. Other trace elements were reported to be below detection limits.

Chemical history. No other chemical data are known from this site.

Sediments. Extractable concentrations of arsenic, boron, copper, vanadium and zinc ranked mid-range among sites within this class. Other trace elements analyzed were reported to be below detection limits. Boron and zinc concentrations exceeded (by small factors) mean concentrations for soils and other surficial materials of the western United States; other reported trace element concentrations were below the regional mean soil concentrations.

Ninepipe Reservoir Pothole

Climatic setting. The net annual precipitation balance for the Ninepipe Reservoir area (from the MAPS database) is -18 inches, placing this site toward the middle of the range of evaporative intensity shown by sample sites of the intermontane valleys. Mean monthly precipitation for the St. Ignatius climatic station shows relatively even distribution with a maximum in May and June. Total precipitation for the St. Ignatius station shows the three-year running average remaining near or above the long-term average from 1980 through 1993. Total precipitation in 1993 (the year prior to sampling) exceeded the long-term average by about 3 inches.

Geologic setting. The Mission Valley generally is underlain by glacial sediments deposited by the southward advance of the late Pleistocene lobe which occupied the Flathead Lake basin. Sediments in the Ninepipe area include till of different textures, glaciolacustrine sediments and outwash in complex stratigraphic sequences. Regional source areas for glacial sediment are mainly underlain by metasedimentary rocks of the Proterozoic-aged Belt series, including calcareous and dolomitic lithologies. Generally the kettle-pitted surface underlying the Ninepipe National Wildlife Refuge and surrounding areas is composed of till of relatively low permeability. Permeable aquifer gravels within the upper 200 feet of the glacial sequence support high-yield wells nearby.

Hydrologic type. The WET53 wetland occupies a small ice-block depression (kettle) within the kettle wetland complex surrounding Ninepipe Reservoir. The wetland receives surface runoff from a restricted area and possibly shallow ground-water inflow from the Post E Canal, situated close by and apparently upgradient from the WET53 wetland. The site is believed to lack surface-water drainage under the present conditions. The permanence of this site is uncertain; the sample collection, however, occurred later in the summer during a generally dry year.

Basin characteristics. The surface catchment and relief of this site are minimal, though impossible to define with any precision using available maps. The water depth is unknown but inferred to be no more than a few feet. Ground-water relationships are also unknown; local pond outflow (restricted by low hydraulic conductivity) probably occurs under at least some conditions. It is possible (though not considered likely) irrigation canal seepage supports ground-water inflow to the site.

Water chemistry. At the time of sampling, the WET53 site contained alkaline "oligosaline" magnesium-carbonate water. WET53 exhibited the highest reacting percent of magnesium seen in the sample set. It also contained an unusually high fraction of chloride for a site of relatively low salinity. Equilibrium calculations indicate substantial oversaturation with respect to carbonate minerals; the poor charge balance shown by this analysis places these

calculations in doubt, however . The ammonium and total organic carbon concentrations ranked mid-range in comparison to regionally and hydrologically similar sites. The orthophosphorous concentration was among the highest found in western Montana sites.

Arsenic, copper and iron concentrations rank mid-range within the site class. Other trace elements were below reporting limits.

Chemical history. No other chemical data from this site are known. The somewhat unusual chloride fraction raises the possibility that low-level contamination with chloride salts is occurring.

Sediments. Reported extractable concentrations of arsenic, vanadium, and zinc ranked mid-range among sample sites of the intermontane basins. Extractable boron, copper, nickel and selenium concentrations were relatively high when compared with western Montana sites lacking mine and mineral processing impacts. The boron and selenium concentrations exceeded the mean concentrations for soils of the western United states by factors of 1.6 and 1.7, respectively. Other trace element concentrations were below the regional mean soil concentrations.

North Goose Lake

Climatic setting. The net annual precipitation balance for Goose Lake derived from the MAPS database is -21 inches, toward the less evaporative end for sites in this class. Based on analyses of evaporation pan data and the hydrologic behavior of Brush Lake, this is a considerable underestimate of the regional water deficit, and points out the need to view the MAPS estimates only as relative indicators of net site precipitation. Mean monthly precipitation for the Grenora climatic station shows a pronounced summertime maximum centered in June. Recent annual totals for the Grenora station are fragmentary. Annual totals for the Medicine Lake station show apparent periodicity with a 5 to 7 year cycle. Throughout the 1980s, the 3-year running average remained below (often well below) the long-term average, recovering in the early 1990s. In 1993 (the year before sampling) precipitation exceeded the long-term average by more than 1 inch.

Geologic setting. Goose Lake occupies an irregular linear depression in the late Pleistocene-aged glacial outwash gravel forming the Clear Lake aquifer. The 5-foot isopach of outwash gravel thickness transects the lake; the southern portion is underlain by a thicker section of outwash, while the thickness of sand and gravel under the northern part of the lake, including the distinct basin known as North Goose Lake, is thin (less than 5 feet). Till and other glacial sediments underlie surfaces outside the lateral extent of the outwash gravels. Surficial glacial materials are underlain by the Fort Union Formation of early Tertiary (Paleocene) age. North Goose Lake lies within the Williston Basin, a structural feature supporting important petroleum and natural gas production. There are producing wells within the immediate vicinity.

Hydrologic type. North Goose Lake is a glacial depression lacking significant surface water inflow and lacking surface water outflow under present conditions. The lake is primarily dependent on ground-water inflow; highly saline lake chemistry implies that ground-water outflow is limited.

Basin characteristics. North Goose Lake is an elongated basin separated from Goose Lake by a low, narrow divide which may be inundated under high-water conditions. The surface catchment of North Goose Lake is minimal, providing one of the lowest catchment to wetland area ratios of the data set. No data on lake depth are available, but most highly saline lakes in the area are relatively shallow.

Water chemistry. At the time of sampling, North Goose Lake contained hypersaline, highly alkaline sodic brine with roughly equal equivalent concentrations of sulfate and CO₂ species and a comparatively high chloride concentration. Calcium and magnesium concentrations are very low (less than 1% of the total cation concentration in meq/l). Mineral equilibria indicate substantial

oversaturation with carbonate phases and approximate equilibrium with mirabilite ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$). Ammonium, total organic carbon and phosphorous concentrations were relatively high.

Most trace element concentrations analyzed were below reporting limits. Arsenic and boron concentrations, however, were at or near the maximum levels found in the sample set. The chromium concentration was one of the two highest reported for sites outside of the southern Montana (unglaciated) plains.

Chemical history. Previous sampling shows North Goose Lake to be subject to large temporal variations in salinity. The available data suggest the lake is fairly well mixed internally at any given time, however. Field measurements of specific conductance in September 1984 showed an 18% increase from the southern to northern ends of the lake. Similar measurements in August 1990 showed essentially no difference in specific conductance or pH between the northern and southern ends of the lake.

Between 1984 and 1990, the specific conductance of North Goose Lake increase by a factor of approximately 2.4; between 1990 and the DHES sampling in 1993, specific conductance increased again by a factor of 1.4. North Goose Lake probably has a Holocene history of complete desiccation during some periods of extreme drought.

The proportionately high chloride concentration (21% of anions as meq/l) and a known history of poor oilfield brine disposal practices in the area raise the possibility that North Goose Lake is subject to some impacts from contaminated ground water. Most of the lake's solute load is interpreted to be of natural origin, however.

Sediments. Relatively high concentrations of calcium and magnesium probably reflect the formation of authigenic carbonate minerals in the North Goose Lake basin. Most trace elements analyzed were below reporting limits in the North Goose Lake sediment sample. Extractable boron was near the upper end of the range shown for sites in the glaciated plains; the extractable arsenic, iron and manganese concentrations were toward the lower end of their respective ranges for this site class.

North Widgeon Slough WPA

Climatic setting. The net annual precipitation balance for North Widgeon Slough (from the MAPS database) is -20 inches, placing this site near the less intensely evaporative end of the range shown by Great Plains sites. (Research on Brush Lake indicates that this value considerably underestimates actual evaporative losses in this area, and emphasizes the need to view these values only as comparative indicators of evaporative intensity.) Mean monthly precipitation for the nearby Westby station shows a broad summertime peak with a June maximum. Annual totals for the Westby station, though incomplete for recent years, show the persistent regional deficit of the 1980s, and totals exceeding the long-term average in the early 1990s. Total precipitation in 1992, the year prior to sampling, was about an inch below the long-term average.

Geologic setting. The North Widgeon Slough area is underlain by a pitted surface of late Wisconsin-aged calcareous glacial till; other glacial deposits of local distribution may occur within the lake catchment. North Widgeon Slough and its catchment are outside of the area of distribution of the Clear Lake aquifer and other permeable gravel aquifer systems. Surficial glacial deposits are underlain by sandstone and shale of the early Tertiary (Paleocene) Fort Union Formation.

Hydrologic type. North Widgeon Slough is an ice-block depression (kettle) with ephemeral channelized surface-water inflow, and lacking surface water outflow under present hydrologic conditions. The relationship of North Widgeon Slough to local ground-water systems is undescribed; both local ground-water inflow and outflow may be inferred for different conditions.

Basin characteristics. Unlike the other smaller sampling sites in the Medicine Lake area (Brush Lake, Comertown Preserve, Mallard Pond, North Goose Lake), North Widgeon Slough has a catchment extending well beyond the wetland basin itself, and a catchment to wetland area ratio ranking mid-range among sampling sites of the glaciated plains. The depth of the slough is unmeasured but inferred to be no more than a few feet. North Widgeon Slough may drain to the northwest during periods of higher precipitation.

Water chemistry. At the time of sampling, North Widgeon Slough contained moderately alkaline "mesosaline" water of sodium-sulfate composition. Mineral equilibria indicate substantial oversaturation with carbonate phases. The ammonium concentration ranks toward the upper end of the range shown for sites in this class; phosphorous (total and orthophosphate) and total organic carbon concentrations rank low to mid-range in comparison to sites in the same classification.

Arsenic and boron concentrations ranked toward the upper end of the ranges shown by sampling sites in this class. Lead and nickel were reported at their respective detection limits. In the case of

nickel, WET55 was one of only five sites with a reportable water column concentration.

Chemical history. A single specific conductance measurement collected in August 1990 from an uncertain point on North Widgeon Slough is the only other chemical information known for this site. The value reported (1510 microsiemens/cm) was almost an order of magnitude lower than at the time of the DHES sampling. The history of North Widgeon Slough probably includes complete desiccation during times of prolonged drought.

Sediments. Relatively high concentrations of extractable calcium and magnesium may reflect deposition of authigenic carbonate minerals in North Widgeon Slough sediments. Extractable concentrations of arsenic, boron and copper were at or near the upper end of the ranges shown for this site class. Iron, nickel, vanadium and zinc ranked mid-range in comparison to other sites in this class. The concentrations of most other trace elements analyzed were below reporting limits. The extractable boron concentration reported exceeded the mean concentration for soils of the western United States by a factor of 4.6; arsenic exceeded the western U.S. soil mean by a factor of 1.25. Other trace element concentrations were equal to or lower than regional mean soil values.

Odell-Skull Creek RNA

Climatic setting. The net annual precipitation balance for the WET56 site (from the MAPS database) is -4 inches, ranking Odell-Skull Creek near the middle of the moisture range shown for Rocky Mountain sampling sites. The available low-elevation climatic data are not considered directly relevant to this subalpine setting, where water supply is probably derived mainly from winter snowpack.

Geologic setting. The wetland and its catchment are underlain by bouldery till deposited on a glaciated surface formed on formations of the Missoula Group, a subset of the Proterozoic-aged Belt series. Areas to the west of the immediate catchment expose large areas of Cretaceous and early Tertiary-aged intrusive rocks with granitic and granodioritic compositions. The wetland is immediately to the east of an area of chemical soil anomalies identified as a potential mineral exploration target.

Hydrologic type. The WET56 site (lower Skull Creek Meadows on published maps) is a headwater area lacking discrete surface water inflow, and having a distinct (perennial?) surface water outlet.

Basin characteristics. The catchment to wetland area ratio ranks mid-range in comparison to other Rocky Mountain sampling sites. WET56 is situated on the downgradient in a series of two wetlands; water storage in the upper wetland may influence the timing and duration of water received by the WET56 site. No information on ground-water behavior in the area is available. The site is vegetated throughout, and the maximum free water depth inferred to be shallow throughout the year.

Water chemistry. Water in Skull Creek Meadows, as represented by the WET56 sample, is very dilute, moderately acidic and sodium-bicarbonate in composition. Mineral equilibria indicate highly undersaturated conditions with respect to carbonate phases. Nitrate and ammonium concentrations were both below reporting limits; phosphorous concentrations were high in comparison to most other Rocky Mountain sites, and the total organic carbon concentration ranked mid-range within the site class.

WET56 was one of the few Rocky Mountain sampling sites with reportable boron and zinc concentrations. The copper concentration was near the upper end of the range shown for Rocky Mountain sites, and was exceeded mainly by sites with known mining impacts. The arsenic concentration ranked mid-range within the site class.

Chemical history. No other water chemistry data are known from this site. Stream sediment samples for mineral exploration may have been collected nearby.

Sediments. The WET56 sediment sample contained a diverse array of extractable trace elements. The vanadium concentration was among

the three highest in the sample set, exceeded only by sites with known mining impacts. WET56 was among the handful of sites with a reportable mercury concentration. Arsenic, boron, copper, selenium and zinc all occurred in detectable concentrations, all ranking mid-range with respect to other Rocky Mountain sites. None exceeded the mean concentrations for soils of the Western United States.

Oilmont Wetland

Climatic setting. The net annual precipitation balance for the Oilmont site (from the MAPS database) is -27 inches, placing Oilmont toward the more intensely evaporative end of the range for the sample sites. Monthly average precipitation for the Sunburst 8E climatic station shows a broad summer peak with a maximum in June. Since the mid-1970's, the 3-year running average of annual precipitation for the Sunburst station was mainly at or above the mean for the period of record. Data for 1993 and 1994 were not recovered for this station; regionally, 1993 totals were well above the average and 1994 totals were below average.

Geologic setting. The Oilmont site is underlain by calcareous till, lying just north of a prominent end moraine marking a late Pleistocene glacial advance. Shorelines and bottom sediments observed under desiccated conditions consist of zoned chemical precipitates and weakly cemented beach sand and gravel.

Bedrock underlying the till is described as an unspecified formation of the Colorado Group. The site is near the apex of the Kevin-Sunburst structural dome and in the midst of the (producing) Kevin-Sunburst oil field.

Hydrologic type. The Oilmont wetland is a saline playa drained by a culvert under higher water conditions, and lacking surface drainage under low water conditions. Surface drainage, when it occurs, is to another small wetland basin to the west.

Basin characteristics. The Oilmont wetland has a small contributing basin and a low ratio of catchment area to wetland surface area. The wetland basin has a very flat, shallow cross-section; the maximum water depth (controlled by the outlet culvert crossing beneath the north-south county road) is estimated to be less than three feet. The drainage of this basin has been altered by road construction, especially by the berm upon which the east-west road to Oilmont is constructed. The existence of this berm appears to impound local runoff in the sampled wetland at the expense of other small playas, once connected, south of the road. Observations by local residents support this inference.

Water chemistry. At the time of sampling in June of 1994, water in this wetland was a "eusaline" sodium sulfate brine with notably low bicarbonate and carbonate concentrations. In September of 1994, there was no surface water at this site. Mineral equilibria indicate that at the time of sampling, the water column was substantially oversaturated with carbonate species and near equilibrium with gypsum.

Orthophosphorous and total phosphorous concentrations at the Oilmont wetland were in the upper third among hydrologically similar sites. Nitrate and ammonium concentrations were both low,

with ammonium below detection limits. The total organic carbon concentration was among the three highest of the sampled wetlands.

The boron concentration at the Oilmont site was among the highest for the sample set. Arsenic and iron concentrations were also relatively high, but well within the range shown by hydrologically similar sites. Other analyzed trace elements were below detection limits.

Chemical history. No chemical data other than that from the June 1994 sampling are known from this site. No prior sampling is known, and when revisited 3 months later the site lacked any free water. Under normal circumstances water levels are now controlled by the combination of a drainage culvert and road berms. No apparent surface water route exists for flushing solutes beyond the neighboring basin linked by culvert to the sample site, and the site may be accumulating salts as a result.

Sediments. Extractable boron and arsenic concentrations are near the high end of the range for hydrologically similar sites. Other trace elements which were detected in sediments occurred near or below median values for hydrologically similar sites. The arsenic concentration exceeded the average value for soils and other surficial material of the western U.S. by about 20%; the boron concentration exceeded the western U.S. average by a factor of four.

The desiccated playa surface displays concentric zonation of precipitate textures and mineralogy. Precipitate facies observed include carbonate cementation of littoral sand and gravel; earthy, anhedral efflorescences on the higher-elevation playa surfaces; and euhedral gypsum(?) near the center of the playa.

Ontario Creek Headwaters

Climatic setting. The net annual precipitation balance for Ontario Creek Headwaters (from the MAPS database) is -3 inches, placing the site near the humid end of the range shown by the sample sites, but mid-range for those in the Rocky Mountains. Mean monthly precipitation for the Basin climatic station (at a much different elevation than the site) shows a bimodal distribution, with a primary June maximum and a secondary January peak. The three-year running average of annual precipitation for the Boulder station (also at some distance from WET58) shows values below the long-term average for much of the 1980s and near or above the long-term average for 1990-93, with precipitation in 1993 (the year of sampling) almost 6 inches above average. [Water supply to the Ontario Creek headwaters is probably supported mainly by winter snowpack, however, which is not reflected in data from these low-elevation stations.]

Geologic setting. The Ontario Creek wetland is underlain by deeply weathered glacial till interpreted as early Wisconsin in age. Glacial deposits, which are probably very thin, overlie the Cretaceous-aged Elkhorn volcanics and quartz monzonite the Boulder batholith. Hydrothermal mineralization has encouraged extensive prospecting and historic ore production at numerous nearby sites along the Ontario Creek-Telegraph Creek divide.

Hydrologic type. WET58 is a small headwaters site with intermittent(?) surface water outflow and without channelized inflow. Although ground-water relationships are not known, the position of the wetland near a drainage divide suggests recharge from the wetland to ground-water may occur.

Basin characteristics. The Ontario Creek wetland is a shallow basin with a small, low-gradient catchment and a low catchment to wetland area ratio in comparison to other Rocky Mountain sampling sites. No mines or prospects are known within the immediate catchment, but some level of sulfide mineralization is probably ubiquitous in the area.

Water chemistry. The Ontario Creek wetland is acidic, extremely dilute and calcium/sodium-sulfate in composition. Nitrogen and orthophosphorous concentrations are very low, and the total organic carbon concentration ranks mid-range in comparison to Rocky Mountain sites.

The copper concentration reported is very high, exceeded in the site class only by sample sites with known mining impacts. Arsenic and iron concentrations rank mid-range within this site class, and lead was reported at the detection limit.

Chemical history. No other chemical data from this site are known.

Sediments. The extractable concentrations of arsenic and copper

rank toward the upper end of the ranges shown for Rocky Mountain sites, with most higher concentrations reported from sites with known mining impacts. Iron, manganese and zinc concentrations rank at or near the lower end of their respective ranges, and other trace element concentrations were below reporting limits.

Ontario Mine Wetland

Climatic setting. The net annual precipitation balance for the Ontario Mine (from the MAPS database) is -3 inches, placing the site near the humid end of the range shown by the sample sites, but mid-range for those in the Rocky Mountains. Mean monthly precipitation for the Basin climatic station (at a much different elevation than the site) shows a bimodal distribution, with a primary June maximum and a secondary January peak. The three-year running average of annual precipitation for the Boulder station (also at some distance from WET59) shows values below the long-term average for much of the 1980s and near or above the long-term average for 1990-93, with precipitation in 1993 (the year of sampling) almost 6 inches above average. [Water supply to the Ontario Creek headwaters is probably supported mainly by winter snowpack, however, which is not reflected in data from these low-elevation stations.]

Geologic setting. The WET59 site is underlain by quartz monzonite of the Boulder Batholith, near the contact with a mass of aplitic intrusive rock underlying O'Keefe Mountain. Surficial deposits are not shown on geologic maps of the immediate area and are probably thin or absent. Historic mine workings drain to the unnamed creek supporting the wetland. No specific information on the nature of mineralization in these particular workings was found. Sulfide mineralization is widespread in the area.

Hydrologic type. The WET59 site is in a headwater riparian wetland area supported by a small first-order stream receiving ground-water discharge which is contaminated by acid mine drainage.

Basin characteristics. The surface water catchment is small and relatively steep; the wetland area is not definable at published map scales. Ground-water delivered as mine drainage may possibly originate outside the boundaries of the surface catchment.

Water chemistry. The water sampled at WET59 is characterized by obvious effects of acid mine drainage (AMD), including very low pH, dominance of the anion makeup by sulfate, and elevated concentrations of metals. Nitrate and ammonium concentrations were below detection limits, the orthophosphate concentration ranked mid-range in comparison to other Rocky Mountain sites. The total organic carbon concentration was among the lowest in the sample set. Arsenic, cadmium, copper, lead and zinc concentrations were the highest among the Rocky Mountain sites. In the case of cadmium, lead and zinc, WET59 showed the highest water-column concentrations in the entire data set.

Chemical history. No other chemical data from this site are known.

Sediments. A very high concentration of extractable iron probably reflects deposition of iron hydroxides precipitated from the water column. Extractable arsenic and lead concentrations are the

highest in the sample set by wide margins. Copper, mercury and zinc concentrations also rank near the upper end of the ranges shown. Arsenic, copper, lead and zinc concentrations exceed mean concentrations for soils of the western United States by one to three orders of magnitude.

Pine Butte Fen

Climatic setting. The net annual precipitation balance for Pine Butte fen (from the MAPS database) is -20 inches, at the humid end of the range shown by Great Plains sites. Mean monthly precipitation for the Blackleaf Canyon climatic station shows a broad summertime peak with a June maximum. Total annual precipitation records at the Blackleaf Canyon station are incomplete for recent years; reported totals since 1990 were above the long-term average for the station, with total precipitation in 1993 (the year of sampling) exceeding the long-term average by more than 7 inches.

Geologic setting. Pine Butte Fen occupies a broad area of ground-water discharge from shallow aquifers recharged largely by seepage from the channel of the Teton River. The unconsolidated aquifer supporting the fen is composed of calcareous outwash and alluvium of late Pleistocene age, deposited near the terminus of an alpine glacier flowing out of the Teton River canyon (nearby to the northwest.) Reduced aquifer cross-sectional area and upward potentiometric gradients drive ground-water discharge to the fen.

The outwash gravel and other surficial sediments overlie shale, siltstone and minor sandstone of the late Cretaceous-aged Two Medicine and Telegraph Creek Formations. Cretaceous rocks are believed to behave mainly as boundaries to ground-water flow through surficial materials.

Hydrologic type. Pine Butte Fen is an area of perennial ground-water discharge from calcareous unconsolidated aquifers deposited as outwash immediately beyond the local limits of alpine glaciation. Surface water inflow from the small surface catchment is a minor component of the fen water budget; ground-water discharge supports perennial surface water outflow from the fen.

Basin characteristics. Low topographic divides describe a surface catchment only slightly larger than the fen itself; ground-water supporting the fen originates as recharge outside the local surface catchment. Most of the fen is vegetated; up-welling ground-water maintains limited open-water pools of undescribed(?) depth. The underlying aquifer narrows and probably thins to the southeast, generating the ground-water discharge which supports the fen and perennial outflow by two spring creeks to the North Fork of Willow Creek.

Water chemistry. Water sampled at WET60 is dilute, slightly alkaline and calcium-bicarbonate in composition. Mineral equilibria indicate oversaturation with carbonate phases. Trace element concentrations generally are low; iron and zinc were reported at intermediate concentrations and most other trace element concentrations were below reporting limits.

Chemical history. No other chemical data for WET60 were found.

Some additional water quality data may be available from The Nature Conservancy, however.

Sediments. Arsenic, boron and vanadium concentrations rank mid-range among sites in this class. Iron and selenium concentrations were comparatively high, as was iron (suggesting and boron and zinc concentrations low within the site class. Most other trace elements occurred at concentrations below reporting limits. Arsenic and selenium exceeded mean values for soils of the western United States by factors of 1.25 and 2.6, respectively. Other trace elements analyzed were below the regional mean soil concentrations.

Sands Waterfowl Production Area

Climatic setting. The net annual precipitation balance for the Sands WPA (from the MAPS database) is -27 inches, placing Sands toward the more evaporatively intense end of the range shown for sites of the glaciated plains. Mean monthly precipitation for the Havre climatic station shows a prominent June maximum. Total annual precipitation for the Havre station shows apparent periodicity, with peaks in the 3-year running average every 4 or 5 years. From 1988 to 1990, the running average was below the long-term mean. From 1991 through 1993, the running average met or exceeded the long-term average.

Geologic setting. The WET61 site (part of the Sands WPA situated on Halfway Lake, but not to be confused with nearby Sands Lake) is underlain sandstone and shale of the late Cretaceous Judith River Formation and, at the northern end of the lake, the late Cretaceous Bearpaw Shale. The catchment contributing to Halfway Lake exposes significant areas of Tertiary volcanic rocks in addition to the sedimentary rocks underlying Halfway Lake. Surficial deposits are inferred to include lacustrine sediments within the lake basin and glacial deposits(?) in lower-elevation portions of the Halfway Lake catchment; descriptions of surficial sediments are not available for the area, however.

Hydrologic type. Halfway Lake has surface water inflow from a large catchment and no apparent surface water outflow. The origin of the lake basin is uncertain; glacial processes and structural geologic controls may both contribute to the basin's presence.

Basin characteristics. Halfway Lake has a relatively large natural catchment and a catchment to wetland area ratio ranking mid-range among Great Plains sampling sites. Water is also imported into the catchment from the Beaver Creek basin to the west; some of this imported water may contribute to Halfway Lake. The depth and volume of the lake are unknown, but low basin gradients suggest shallow lake depths and transient shoreline position. The WET61 site is very near one the lake's inlet streams and may during runoff conditions show more dilute water chemistry than other point in the lake.

Water chemistry. At the time of sampling, WET61 exhibited near-neutral, "oligosaline" sodium-bicarbonate water quality characteristics and a depressed dissolved oxygen concentration. The sampling hour (8:30 am) suggests that the DO depression may be due to overnight plant respiration in a productive setting. The ammonium concentration ranked mid-range in comparison to sites in this classification; phosphorous and total organic carbon concentrations were high, with the phosphorous concentrations (total and orthophosphate) exceeded mainly at sites much more saline than Halfway Lake.

Arsenic and boron concentrations rank mid-range within this site class, while copper, iron, lead and zinc concentrations were

comparatively high.

Chemical history. No previous chemical data are known from this site. The salinity of Halfway Lake represented by the DHES analysis is low for a site in the plains which apparently lacks surface water outflow. Sample collection occurred during high lake stage and may also have reflected the proximity of WET61 to a contributing drainage.

Sediments. Arsenic, boron, iron, nickel, vanadium and zinc concentrations all rank mid-range among sites of the glaciated plains, but are lower than for most plains sites lacking surface water outflow. The boron concentration exceeds the mean concentration for soils and other surficial materials of the glaciated plains by a small factor; other trace element concentrations analyzed are below the regional mean soil concentrations.

Schrammeck Lake WPA

Climatic setting. The net annual precipitation balance for Schrammeck Lake (from the MAPS database) is -25 inches, an intermediate value for hydrologically similar sampling sites. Monthly average precipitation for the Cascade climatic station shows a strong May-June peak. Annual records for the Cascade station show the 3-year running average at or above the long-term average for most of the past 20 years. The annual total in 1993, the year prior to sampling, exceeded the long-term mean by about 3 inches.

Geologic setting. The Schrammeck Lake basin is underlain by bentonitic shale and sandstone of the Colorado group. Colorado Group sediments in the area reportedly include pebble conglomerates derived from the phosphatic Phosphoria Formation.

The area is beyond the maximum advance of Pleistocene glaciation. Surficial sediments observed in and around the lake include lacustrine sediments ranging from organic-rich, highly reduced sticky mud to relatively well-sorted, fine to medium-grained calcareous littoral sand on the northern shoreline. Vegetated ridge-and-swale features at the northern end of the lake may be small dunes, suggesting past desiccation of the lake. The lake exhibits at least one relict shoreline at an elevation approximately 10 feet above the observed lake stage, indicating lake volume more than an order of magnitude greater than at the time of sampling. In nearby Geyser Creek, groundwater discharge reportedly causes small "eruptive" features in weathered Colorado Group sediments.

Hydrologic type. Schrammeck Lake is a nonglaciaded (probably structurally controlled) basin lacking surface outflow. Surface outflow has probably occurred at higher water levels, shown topographically by an apparent outflow channel north of the wetland. Ground-water outflow through winnowed littoral sediments may occur.

Basin characteristics. Schrammeck Lake has a relatively small surface catchment with respect to the area of the wetland. At current water levels the volume of Schrammeck Lake is low relative to its surface area. The maximum measured water depth in August of 1994 (at somewhat lower stage than during sampling) was 1.4 feet, with little variability across the open water portion of the basin.

Water chemistry. Schrammeck Lake water is a sodium carbonate type, of moderate salinity at the time of sampling. This major-ion water composition is unique within the wetland sample set. Equilibrium calculations indicate substantial oversaturation with carbonate species.

Schrammeck Lake shows relatively high water-column concentrations of several trace elements, including boron, chromium, iron, lead

and zinc. Relative to hydrologically similar sites, however, none of these concentrations appear extraordinary.

Orthophosphorous and total phosphorous concentrations were near the maximum for all sample sites, while both nitrate and ammonium concentrations were below detection limits. Total organic carbon was within the range shown by hydrologically similar sites.

Chemical history. No water quality data predating the DHES sampling are known. Observations during June, August and September of 1994 showed a threefold seasonal increase in specific conductance during 1994. In August of 1994, measured specific conductance within the wetland varied spatially by no more than 3%. Schrammeck Lake has probably experienced both desiccation and overflow during the recent geologic (and possibly historic) past. Water quality at the high stage indicated by relict shoreline features would probably be quite dilute, approaching the concentration of runoff from similar geologic materials.

Sediments. Schrammeck Lake sediments contain trace element concentrations within the range shown by hydrologically similar sample sites. Extractable concentrations of boron and zinc exceed regional mean values for soils and other surficial materials in the western U.S.

Spidel Waterfowl Production Area

Climatic setting. The net annual precipitation balance for the Spidel WPA (from the MAPS database) is -29 inches, ranking this as one of the most intensely evaporative sites in the data set. Mean monthly precipitation for the Broadview climatic station shows a maximum in May; annual totals for the Broadview station are incomplete but show generally below-normal values during the 1980s. Annual totals after 1990 were not recovered for this station. Regionally, precipitation totals for 1991 through 1993 were above average for many stations.

Geologic setting. The Spidel basin is a depression along the western limb of the Bull Mountains structural basin. The Spidel basin itself appears to be structurally controlled; WET63 is underlain by the Lance Formation of latest Cretaceous age; western portions of the Spidel catchment are underlain by the Bearpaw Shale and Judith River Formations of late Cretaceous age, while the eastern portion of the catchment is underlain by the Fort Union Formation of early Tertiary age. The central portion of the Spidel basin has accumulated an unknown thickness of lacustrine sediments.

Hydrologic type. The Spidel wetland occupies a basin lacking surface water outflow, and receiving surface water inflow from a number of intermittent drainages. Local ground-water inflow may also occur but probably is not volumetrically important. The surface extent and shoreline position of the Spidel wetland is inferred to be highly variable.

Basin characteristics. The Spidel basin has a large catchment and, based on the mapped extent of the wetland, a catchment to wetland area ratio intermediate with respect to other sample sites of the unglaciated great plains. A number of small impoundments within the catchment may have altered the quantity and timing of runoff received by the Spidel basin. The low gradient basin implies large variations in surface area; water depths are unknown but inferred to be no more than a few feet.

Water chemistry. At the time of sampling, the Spidel WPA contained transition "oligosaline/mesosaline" sodium sulfate water of moderately high alkalinity. Mineral equilibria indicate substantial oversaturation with carbonate phases. The ammonium concentration was low in comparison both to unglaciated plains sites and to other sites lacking surface water outflow. Phosphorous concentrations ranked mid-range with respect to regionally and hydrologically similar sites, and the total organic carbon concentration was comparatively high.

Arsenic, boron and iron concentrations ranked mid-range in comparison to other sites in this class. Most other trace element concentrations were below reporting limits.

Chemical history. No other chemical data from this site are known.

The basin configuration and climatic setting imply wide variability in salinity at this site; late summer and fall dissolved solids concentrations may be several times that observed at the time of sampling.

Sediments. Extractable arsenic, copper, nickel and zinc concentrations ranked mid-range or below in comparison to other unglaciated plains sites. Boron, chromium, iron and vanadium concentrations ranked relatively high, and the selenium concentration was among the three highest reported for the entire data set.

The selenium concentration exceeded the mean concentration for soils of the western United States by a factor of 3, and the boron concentration exceeded the regional mean soil concentration by a factor of 2.4. The extractable nickel and zinc concentrations exceeded regional mean soils concentrations by small factors.

Swamp Gulch

Climatic setting. The net annual precipitation balance for Swamp Gulch (from the MAPS database) is -4 inches, mid-range among Rocky Mountain sites. Mean monthly precipitation for the Lincoln Ranger Station climatic station shows a late spring peak, with relatively even distribution the remainder of the year. (Water supply in the headwater streams contributing to the Swamp Gulch wetland probably are much more heavily influenced by winter snowpack than is the Lincoln climatic station.) Annual total precipitation for the Lincoln station was generally below average during the mid-1980s and near or above the long-term average in the late 1980s and early 1990s. Total precipitation in 1993 (the year of the DHES sampling) exceeded the long-term average by about 5 inches.

Geologic setting. The Swamp Gulch wetland and upstream catchment areas are underlain mainly by the Spokane and Empire formations of the Proterozoic-aged Belt series; late-Proterozoic mafic intrusive rocks (diorite) also occur in the lower Swamp Gulch drainage. Early Tertiary-aged monzonite porphyry and intrudes the Proterozoic-aged rocks near the mouth of Swamp Gulch; mineralization of the diorite near this intrusive contact was developed by the abandoned Carbonate Mine. Drainage from the Carbonate Mine enters lowermost Swamp Gulch and the WET64 wetland area. The immediate wetland area is underlain by undescribed alluvial (and glacial?) sediments and by up to 15 feet of peat and other palustrine sediments.

Hydrologic type. The Swamp Gulch wetland is a complex of low-gradient riparian and ponded areas at the confluence of streams forming the upper Blackfoot River. Surface water inflow occurs from several streams. Surface-water outflow is to the Blackfoot River. Ground-water movement through the wetland occurs through peat and presumably through the underlying unconsolidated sediments, probably discharging to the Blackfoot River downstream of the WET64 site.

Basin characteristics. The Swamp Gulch wetland has a substantial catchment and a relatively high catchment to wetland area ratio. Water sources in the immediate WET64 area include both Swamp Gulch and the Upper Blackfoot River, which is formed a short distance upstream by the confluence of Pass Creek and Anaconda Creek. Blackfoot River water is carried past the WET64 site by beaver ponds and a minor diversion channel. The distribution of ponds and channels within the wetland area surrounding the WET64 site is believed to have been stable throughout the twentieth century.

The overall thickness of peat and other high-organic sediments is on the order of 3 feet or less, with 3 to 12 feet of silty "catotelm" beneath. Ground-water flow through the shallow organic peat is relatively rapid and occurs along preferential flow paths.

At least two of the several streams entering the wetland complex

(Anaconda Creek and Swamp Gulch) suffer serious mining or mineral processing impacts. The Swamp Gulch wetland has functioned as a physical and geochemical sink for some of the mine wastes transported out of these drainages.

Water chemistry. The water sampled at the WET64 site is dilute, mildly acidic, calcium-sulfate in composition, and heavily impacted by acid mine drainage (AMD) from the Carbonate Mine in lower Swamp Gulch. Equilibrium calculations indicate highly undersaturated conditions with respect to carbonate minerals. Nitrate and ammonium concentrations were below detection limits, and orthophosphate and total organic carbon concentrations were near the lower end of the ranges shown for the sample set.

Copper, iron, lead and zinc concentrations were near the upper end of the ranges shown for Rocky Mountain sites, and were generally exceeded only at other sites exhibiting impacts from mining or mineral processing. The arsenic concentration was comparatively low, cadmium occurred at the reporting limit, and other trace elements analyzed were below reporting limits.

Chemical history. The development of the Carbonate Mine predates 1933, and mine drainage has presumably been impacting the WET64 site since that era. Detailed data collection on this site was conducted as part of a 1987 investigation into the AMD-treatment capability of the wetland (see Dollhopf et al in the WET64 site bibliography). None of the sampling sites used in the 1987 study correspond to the WET64 site; the 1987 sampling sites show considerable spatial variability within the general area receiving inflow from Swamp Gulch. pH values below 3, sulfate concentrations in excess of 400 mg/l, and cadmium concentrations in the mg/l range were reported for sampling points near the Swamp Gulch outfall. In contrast to the DHES sample, measurable nitrate concentrations were reported for almost all of the samples analyzed in 1987 and 1988, with concentrations in the mg/l range at several sites.

Sediments. The Swamp Gulch sediment sample was heavily contaminated with metals precipitated from AMD inflow to the wetland. Extractable iron accounted for approximately a third of the sample. Boron, copper, cadmium, cobalt, nickel, vanadium and zinc concentrations were the maximum reported for Rocky Mountain sites and in many cases for the entire data set. Extractable boron, cadmium, iron, and zinc concentrations exceeded those for all other sample sites by several hundred percent. Most trace elements with reportable concentrations exceeded mean soil concentrations for the western United States, in the case of boron, copper and zinc by more than an order of magnitude.

Swan River Research Natural Area

Climatic setting. The net annual precipitation balance for the Swan River site (from the MAPS database) is -8 inches, placing the site toward the more evaporative end of the range shown by Rocky Mountain sample sites. Mean monthly precipitation for the Swan Lake climatic station shows a bimodal distribution, with a major winter maximum and a secondary June peak. Annual totals for this station were not available for years after 1990; the late 1980s experienced annual precipitation below the average for the period of record.

Geologic setting. The WET65 site lies near the contact between Recent alluvium of the Swan River and upland slopes composed of late Pleistocene-aged glacial till described as relatively loose and sandy. Ground-water discharge (from glacial sediments?) occurs nearby to the west, supporting a peat dome centered around the discharge area. Low hills immediately to the east are interpreted as remnants of a kame terrace, supporting a glacial origin for sediments immediately underlying the wetland. The surficial till mantle of upland slopes is underlain by the Helena Formation, a calcareous and dolomitic unit of the Proterozoic-aged Belt series.

Hydrologic type. The WET65 site is in a flow-through setting with surface water inflow and outflow; the site may also receive some ground-water inflow discharging from glacial deposits underlying upland slopes to the east and west or from the alluvial sediments underlying the site, which appear to narrow and thin in the (inferred) downgradient direction.

Basin characteristics. The surface catchment contributing to this site includes upland areas in the Mission Mountain foothills, and (apparently) the western third of the Swan River floodplain for several miles upstream. Ground-water inflow from a larger area may contribute to the wetland, depending on flow paths within the Swan River alluvium. The geometry of the valley-margin channel along which the wetland lies may contribute to local ground-water discharge.

Based strictly on map relationships from the 1965 topographic coverage of the area, the WET65 wetland appears to be at some risk of losing its main source of surface-water inflow. The unnamed stream flowing through the wetland bifurcates (according to the 1965 mapping) a half mile upstream from WET65. The eastern channel bypasses the wetland site, and according to the 1965 topographic mapping appears to be establishing a lower base level than the channel supporting the wetland. Stream piracy could change water availability at WET65 if this process continues.

Water chemistry. The water sampled at WET65 is dilute, circumneutral in pH and of calcium-bicarbonate composition. Mineral equilibria indicate approximate saturation with calcite and undersaturation with respect to dolomite. The nitrate

concentration reported ranks high among Rocky Mountain sites, while orthophosphorous and total organic carbon concentrations rank mid-range within the site class. Trace element concentrations analyzed were low, with the exception of zinc, which ranked high in comparison to the site class, and lead (which was detected at the reporting limit).

Chemical history. No other chemical data are known from this site.

Sediments. Extractable arsenic and iron concentrations rank toward the upper end of the ranges shown for Rocky Mountain sites. Copper and zinc concentrations ranked mid-range or lower in comparison to the site class, and most other trace element concentrations were below reporting limits. The arsenic concentration reported exceeded the mean value for soils of the western United States by a factor of 1.4.

Telegraph Creek Headwaters

Climatic setting. The net annual precipitation balance for the Telegraph Creek Headwaters (from the MAPS database) is -3 inches, placing the site near the humid end of the range shown by the sample sites, but mid-range for those in the Rocky Mountains. Mean monthly precipitation for the Basin climatic station (at a much different elevation than the site) shows a bimodal distribution, with a primary June maximum and a secondary January peak. The three-year running average of annual precipitation for the Boulder station (also at some distance from WET66) shows values below the long-term average for much of the 1980s and near or above the long-term average for 1990-93, with precipitation in 1993 (the year of sampling) almost 6 inches above average. [Water supply to the Telegraph Creek headwaters is probably supported mainly by winter snowpack, however, which is not reflected in data from these low-elevation stations.]

Geologic setting. The Telegraph Creek wetland is underlain by deeply weathered glacial till interpreted as early Wisconsin in age. Glacial deposits, which are probably very thin, overlie the Cretaceous-aged Elkhorn volcanics and quartz monzonite the Boulder batholith. Hydrothermal mineralization has encouraged extensive prospecting and historic ore production at numerous nearby sites along the Ontario Creek-Telegraph Creek divide.

Hydrologic type. WET66 is a small headwaters site with intermittent(?) surface water outflow and without channelized inflow. Although ground-water relationships are not known, the position of the wetland near a drainage divide suggests recharge from the wetland to ground-water may occur.

Basin characteristics. The Telegraph Creek wetland is a shallow basin with a small, low-gradient catchment and a low catchment to wetland area ratio in comparison to other Rocky Mountain sampling sites. No mines or prospects are known within the immediate catchment, but some level of sulfide mineralization is probably ubiquitous in the area.

Water chemistry. The Telegraph Creek wetland is characterized by dilute, mildly acidic calcium-bicarbonate/sulfate water distinctly different in major-ion chemistry from that of the nearby Ontario Creek Headwaters site (WET58). The dissolved solids concentration and pH are considerably higher at the Telegraph Creek site, and the sulfate concentration proportionately much lower. Ammonium and phosphorous concentrations are also higher at WET66, with the orthophosphate concentration ranking toward the upper end of the range shown by Rocky Mountain sites.

The arsenic, boron, copper, iron and lead concentrations in the WET66 sample were all relatively high, exceeded in the Rocky Mountain sites mainly by sites with known mining and mineral processing impacts. Other trace elements analyzed were below

reporting limits.

Chemical history. No other chemical data from this site are known.

Sediments. The sediment sample from WET66 exhibited a generally enriched array of trace elements. Arsenic, boron, iron, and vanadium concentrations ranked toward the upper end of ranges shown for Rocky Mountain sites, with the arsenic concentration exceeded only at mine-impacted or hypersaline sites. Only arsenic exceeded the mean values for soils of the western United States (by a factor of 5.5).

Tew Waterfowl Production Area

Climatic setting. The net annual precipitation balance for the Tew WPA (from the MAPS database) is -27 inches, ranking Tew toward the more intensely evaporative end of the range shown by the data set. Mean monthly precipitation for the Broadview climatic station shows a maximum in May; annual totals for the Broadview station are incomplete but show generally below-normal values during the 1980s. Annual totals after 1990 were not recovered for this station. Regionally, precipitation totals for 1991 through 1993 were above average for many stations.

Geologic setting. WET67 is located on a small structurally controlled(?) basin underlain by the Lebo Shale Member of the early Tertiary Fort Union Formation. Descriptions of the surficial sediments overlying the Fort Union Formation are not available, but they are inferred to consist of relatively thin and locally derived lacustrine or paludal deposits.

Hydrologic type. The WET67 site is a small area of internal drainage lacking discrete surface water inflow or outflow under present hydrologic conditions. Inflow is inferred to be by local runoff and direct precipitation.

Basin characteristics. The small local catchment provides this site with a low catchment to wetland area ratio. At low stages separate water bodies apparently exist within the mapped catchment; during wet conditions the sampled wetland may merge with an adjacent water body outside of the local catchment. Some ground-water outflow may occur, but the basin sediments are probably of low permeability and unlikely to allow very rapid ground-water recharge. The wetland basin has apparently been modified by the construction of the county road adjacent to the WET67 site; this modification may alter the geometry of the water body during high-stage conditions. The water depth of the wetland is unknown but inferred to be shallow.

Water chemistry. At the time of sampling, the Tew wetland contained moderately alkaline, "oligosaline" water lacking a dominant anion or cation. Mineral equilibria indicate oversaturation with carbonate phases. The equivalent concentration of chloride is high compared to most sample sites. The nitrate concentration was below reporting limits and the ammonium concentration was low in comparison to other sites of the plains. Phosphorous concentrations, however, were very high, exceeded only at a few hypersaline or seasonal, closed-basin sample sites. The total organic carbon concentration was among the lowest in the sample set.

Most of the trace elements analyzed occurred in concentrations below reporting limits. The iron concentration ranked near the top of the range shown by plains sites, the arsenic concentration ranked mid-range and the boron concentration was the lowest

reported for any sample site of the unglaciated plains.

Chemical history. No other chemical data are known for this site. By inference, the salinity of this site probably reaches considerably higher levels than shown by the DHES sample.

Sediments. Extractable concentrations of chromium, manganese, nickel and vanadium rank near or (in the case of chromium) at the high end of the ranges shown for unglaciated plains sample sites. Arsenic, boron, copper, iron and zinc ranked mid-range with respect to the site class. Other trace extractable element concentrations occurred in concentrations below reporting limits.

Tooley Lake

Climatic setting. The net annual precipitation balance for Tooley Lake (from the MAPS database) is -14 inches, at the more evaporatively intense extreme of the range shown by Rocky Mountain sites. Mean monthly precipitation at the Eureka Ranger Station climatic station shows a relatively even distribution throughout the year with a maximum in June. Annual totals for the Eureka station show the short-term (3-year) moving average at or above the average for the period of record from 1981 through 1993. In 1993 (the year prior to sampling) the total precipitation exceeded the mean by about 5 inches.

Geologic setting. Tooley Lake occupies a depression of uncertain origin along the margin of a thick sequence of glaciolacustrine sediments deposited during late Pleistocene impoundment of the Kootenai River. The glaciolacustrine sediments are described as predominantly fine sand and silt with only a minor clay fraction. The permeability of these sands and silts appears to be higher than for many lacustrine deposits; ground-water flow is shown by reported behavior during well drilling and by spring discharges from the sediments. Upslope areas within the lake catchment are underlain by drumlinoid till described as bouldery in texture.

Bedrock outcrops within the lake catchment are composed of formations of the mainly argillitic Ravalli Group of the Proterozoic Belt series. Adjacent drainages expose areas of the calcareous and pyritic Siyeh Formation of the Belt series.

Hydrologic type. Tooley Lake has intermittent(?) surface water inflow but lacks surface water outflow. Relatively dilute water chemistry in this setting appears to imply significant ground-water outflow from the lake to moderate the accumulation of solutes contributed by lake inflow. Tooley Lake is also in a topographic position suggesting the likelihood of ground-water inflow along its western shore.

Basin characteristics. The catchment to wetland area ratio ranks mid-range with respect to other Rocky Mountain sites. The depth of Tooley Lake is unknown. Ground-water outflow rates may have been altered by the filling of Lake Koocanusa, artificially raising the local hydrologic base level. Road construction along the eastern shore may have altered shoreline characteristics.

Water chemistry. The WET68 sample was moderately dilute, calcium/magnesium-bicarbonate/carbonate in composition, and only slightly basic in the field. Mineral equilibria indicate approximate saturation with calcite and aragonite under field conditions. The pH measured in the lab, however, was 9.3, indicating that the sample was not in equilibrium with the surface environment. The one other known pH measurement from Tooley Lake was also above 9. A probable explanation is that ground-water enters the lake along the western shore, increasing in pH as inflow

equilibrates with surface CO₂ pressures. This process would allow the precipitation of authigenic carbonate minerals, which is not inconsistent with the relatively high concentration of calcium seen in the Tooley Lake sediment sample.

The ammonium and phosphorous (total and orthophosphate) concentrations reported were high in comparison to the Rocky Mountains sample sites, while the total organic carbon concentration ranked mid-range against the class including WET68. Trace element concentrations were also uniformly low; copper and iron concentrations ranked mid-range or lower, while other trace elements were below reporting limits.

Chemical history. Three previous measurements of specific conductance at uncertain points in Tooley Lake are known, all higher than the 435 microsiemens/cm recorded in August 1994. June and October, 1968 measurements were 670 and 800 microsiemens/cm, respectively; in July, 1988 a measurement of 550 microsiemens/cm was recorded. The pH measurement of 9.3 accompanying the 1988 specific conductance measurement is the only other known chemical measurement from Tooley Lake.

Substantial gradients in pH and in cation distribution probably exist within Tooley Lake, as apparent ground-water inflow circulates through the lake basin and equilibrates with atmospheric conditions.

Sediments. The relatively high extractable calcium concentration is consistent with some level of authigenic carbonate precipitation from influent ground water. Extractable arsenic and copper concentrations rank toward the lower end of the range shown by Rocky Mountain sites, while boron, selenium and zinc concentrations rank mid-range within the site class. Most other extractable trace element concentrations were below reporting limits. None exceeded the mean concentrations for soils and other surficial materials of the western United States.

Townsend Valley Wetland

Climatic setting. The net annual precipitation balance for the Townsend Valley wetland is -28 inches, placing the site at the more intensely evaporative extreme of the range shown by western sampling sites. Mean monthly precipitation for the Townsend climatic station shows a broad summer peak with a June maximum. During most of the 1980s and early 1990s, annual precipitation for the Townsend station was below the average for the period of record. Precipitation in 1993 (the year prior to sampling) exceeded the average by more than 5 inches; regionally, 1994 precipitation was below average at many stations.

Geologic setting. The WET69 site is underlain by Recent alluvium deposited by the Missouri River; tributary alluvium and older Quaternary terrace deposits bound the Recent alluvium, which overlies Tertiary-aged valley fill sediments. Shallow water table depths apparently result in ground-water discharge to depressions such as the WET69 wetland.

Hydrologic type. The WET69 site occupies a depression of unknown origins lacking apparent surface-water outflow or significant surface-water inflow. Ground-water discharge to the wetland is inferred from shallow local water table depths, chemical characteristics and the lack of a significant surface catchment in an area of net annual evaporation. Ground-water outflow also probably occurs, based on the relatively dilute character of the WET69 sample.

Basin characteristics. The WET69 site has a very small surface catchment substantially modified by human activities. Two transportation corridors (State Highway 12 and an active railroad line) closely bracket the site. Irrigation may contribute to the shallow water table depths supporting the wetland.

Water chemistry. At the time of sampling, water in the WET69 wetland was near-neutral, "oligosaline", and sodium-calcium-magnesium/bicarbonate in character. The pH of the sample was unstable, rising from 7.6 in the field to a lab value of 8.7. Mineral equilibria indicate approximate saturation with calcium carbonate phases. The proportional chloride concentration (>11% of anion equivalency) is higher than most sample sites of the intermontane valleys. The cation distribution is distinct from most ground-water analyses from the Missouri River alluvial gravels, which tend to have calcium as the proportionately highest cation.

The ammonium and total organic carbon concentrations at this site ranked toward the upper end of the ranges shown by western sample sites. Phosphorous concentrations ranked mid-range or lower.

The recoverable boron concentration at WET69 ranked near the upper end of the range shown for sites of the intermontane valleys and western sample sites overall. Arsenic, copper, zinc and lead (slightly above the reporting limit) also ranked relatively high in comparison to intermontane valley sites, exceeded mainly at wetlands experiencing known impacts from mining and mineral processing.

Chemical history. No other data from this site are known

Sediments. The relatively high extractable calcium concentration may in part reflect authigenic carbonate precipitation from influent ground water. Extractable concentrations of trace elements are generally high; arsenic, boron, copper, and lead rank near the upper end of the ranges shown for the intermontane valleys and among western are exceeded mainly at those with known impacts from mining and mineral processing. Arsenic, boron, copper, lead and zinc exceed the geometric mean soil concentrations for the western United States by factors of 5.5, 3.6, 3.9, 5.8 and 2.3 respectively.

Turtle Lake

Climatic setting. The net annual precipitation balance for Turtle Lake (from the MAPS database) is approximately -11 inches. This places the site toward the less evaporative end of the climatic spectrum for hydrologically similar sample sites, but toward the more evaporative extreme for Rocky Mountain sample sites. Monthly average precipitation for the Fortine climatic station shows relatively even distribution throughout the year, with a moderate peak in May and June. Annual records from the Fortine station show the 3-year running average precipitation has been below the long-term mean during most of the last 30 years. Annual precipitation during the sample year of 1993 exceeded the average for the period of record by approximately 5 inches.

Geologic setting. The Turtle Lake basin is underlain by calcareous till and possibly other glacial sediment types of late(?) Wisconsin age. Bedrock geologic units are of the Proterozoic Belt Series, probably including the calcareous and dolomitic Helena Formation.

Hydrologic type. Turtle Lake is a glacial depression with surface water inflow from an intermittent stream but lacking surface water outflow at current water levels. Groundwater outflow is inferred from the moderate salinity of this topographically closed basin, contrasting with nearby Thirsty Lake, which has high salinity and apparently restricted ground-water outflow.

Basin characteristics. Turtle Lake has a larger surface catchment and considerably larger catchment to wetland area ratio than nearby Alkali Lake. The cluster of lakes in the vicinity display disjunct water quality; Thirsty Lake, nearby and at a lower elevation, exceeds Turtle Lake and Alkali Lake in specific conductance by more than an order of magnitude. Alkali Lake and Turtle Lake display generally similar water chemistry.

Water chemistry. Turtle Lake is proportionately high in magnesium and is nearly depleted in calcium; equilibrium calculations indicate supersaturation with calcium and magnesium carbonate species. Low calcium concentrations appear to be maintained by solubility controls; deposition of authigenic carbonate minerals is inferred from relatively high extractable calcium concentrations in sediment and from observed marl formation in nearby Alkali Lake. High relative magnesium concentrations are typical of hydrologically similar sample sites.

The ammonium and total organic carbon concentrations rank toward the upper end of the ranges shown by Rocky Mountain sites. The orthophosphorous concentration ranks mid-range in comparison to the site class. Trace element concentrations are comparatively low with the exception of selenium, which was reported at the detection limit.

Chemical history. A single previous partial chemical analysis from this water body is known. Dating from June of 1987, this partial

analysis showed specific conductance of about 80% that measured for the DHES sample, lower pH and alkalinity, and lower (possibly erroneous) cation concentrations.

Sediments. The comparatively high extractable calcium concentration probably reflects authigenic carbonate formation in Turtle Lake. Most extractable trace element concentrations were below reporting limits. Arsenic, iron and zinc concentrations were comparatively low, while the selenium concentration reported ranked toward the upper end of the range shown by this site class.

Upper Red Rock Lake

Climatic setting. The net annual precipitation balance for Upper Red Rock Lake is -5 inches, at the less evaporative extreme of the range shown by sample sites of the intermontane valleys. Mean monthly precipitation for the Lakeview climatic station shows relatively even seasonal distribution with a maximum in June. Annual precipitation totals for the Lakeview station shows an apparent periodicity, with peaks in the 3-year running average occurring every 5 to 7 years. During the late 1980s and early 1990s, the station recorded an unusually deep and extended period of precipitation deficit with respect to the average for the period of record. Precipitation during 1993 (the year of sampling) exceeded the average by about 3 inches.

Geologic setting. The WET71 site is underlain by lacustrine deposits of undescribed thickness and character. Alluvial fan deposits shed from the Centennial Mountain scarp immediately to the south may interfinger with lacustrine deposits. Bedrock exposed within the Upper Red Rock catchment includes a wide variety of lithologies and ages; Paleozoic and Mesozoic-aged sediments comprise much of the Centennial Mountains, while uplands to the north of the lake expose large areas of Quaternary-aged volcanic rocks.

Major faults underlie the Centennial Valley and exert controls on topography, sedimentation and ground-water flow. Geochemical and thermal evidence indicate the discharge of deeply circulating ground water into shallow aquifers north of the lake and into the northern side of Upper Red Rock Lake itself.

Hydrologic type. Upper Red Rock Lake is a natural structurally controlled(?) basin modified by outlet controls designed to stabilize lake water levels. The lake has surface water inflow and outflow and also receives some ground-water inflow from a deeply circulating geothermal system.

Basin characteristics. Upper Red Rock Lake has a large high-elevation catchment and a catchment to wetland area ratio which ranks mid-range among intermontane valley sampling sites. Lake depth and volume are not available. Diversions both for irrigation (in the Alaska Basin upstream) and for fish and wildlife management purposes occur within the catchment.

Water chemistry. Upper Red Rock Lake at the WET71 sampling point contains dilute, moderately alkaline calcium-bicarbonate water. Mineral equilibria indicate slight over-saturation with carbonate phases. Nitrate was reported at a concentration slightly above reporting limits, while ammonium was below reporting limits. The orthophosphate and total organic carbon concentrations ranked toward the lower end of the range shown by sites in this class.

Most measured trace element concentrations were below reporting limits. Arsenic, copper and iron concentrations ranked mid-range within this site class. Chromium was reported at the detection limit, one of only three western sites with quantifiable concentrations.

Chemical history. No other surface water chemistry is known for this site.

Sediments. Extractable arsenic, iron and copper concentrations rank mid-range or lower with respect to this site class, and most other trace element concentrations were below reporting limits. Extractable chromium and zinc concentrations, by contrast, were exceeded only at sites with known impacts from mining and mineral processing. These relatively elevated concentrations may reflect input to the lake basin from geothermal ground water enriched with trace elements.

Upper Stillwater River Wetland

Climatic setting. This site is in a high elevation subalpine setting with a high precipitation surplus. The net annual precipitation balance (from the MAPS database) is 44 inches, one of the two highest values for the sample sites. Mean monthly precipitation for the Cooke City climatic station shows relatively even distribution throughout the year, with low summer and winter peaks. Total annual precipitation for this station shows comparatively low values throughout the later 1980s and early 1990s. Precipitation in 1993 (the year prior to sampling) was near the average for the period of record.

Geologic setting. The WET72 site is underlain by Holocene-aged alluvium and Pleistocene glacial deposits of undescribed character. The surficial deposits cover bedrock lithologies including Tertiary-aged volcanic rocks of silicic to intermediate composition and Cambrian-aged limestone and shale. The upper basin of Daisy Creek, tributary to the upper Stillwater River above the WET72 site, is characterized by extensive hydrothermal mineralization related to the intrusion of the Henderson Mountain Stock and associated dike complex.

Hydrologic type. The Upper Stillwater wetland is a riparian meadow with perennial surface water inflow and outflow during the ice-free season.

Basin characteristics. The alpine and subalpine basin of the Upper Stillwater basin provides a relatively low catchment to wetland area ratio due to the large estimated wetland area. Stream gradients within the wetland are very low. Mine wastes and acid mine drainage (AMD) from the historic McLaren Mine have resulted in severe contamination of upper Daisy Creek, a tributary joining the Stillwater River upstream from the WET72 site. Metal-laden AMD encounters calcareous geologic formations (the Meagher Limestone) a short distance below the McLaren Mine, depositing a hydroxide precipitate as pH rises and removing most dissolved metals from solution. High flows scour the hydroxide solids from Daisy Creek and redeposit them in the stream channel and as overbank sediments in the low-gradient wetland area.

Water chemistry. The WET72 water sample exhibited a dilute, mildly alkaline calcium-bicarbonate character. Equilibrium calculations indicate slight undersaturation with carbonate minerals. Phosphorous (total and orthophosphate) and total organic carbon concentrations were low in comparison to most other Rocky Mountain sites. The ammonium concentration was below reporting limits and the nitrate concentration ranked mid-range in comparison to other Rocky Mountain sites.

With the exception of iron (ranking mid-range in comparison to other Rocky Mountain sample sites), trace element concentrations were below reporting limits in the water column.

Chemical history. Sampling of the WET72 site was carried out in conjunction with a synoptic sampling program on the Stillwater River and it's tributaries which incorporated 16 surface water, sediment and biological sampling stations both above and below the WET72 site. For details, refer to work of the Montana Department of State Lands, Hardrock Bureau of the Reclamation Division. Additional environmental sampling near WET72 may have been conducted by the Crown Butte Mining Company.

Sediments. In contrast to the water column data, the sediments from this site display a generally elevated distribution of trace elements. Extractable concentrations of arsenic, boron, chromium, copper, cobalt, iron, nickel, vanadium, and zinc all are near or at the high end of ranges shown for Rocky Mountain sites and (in most cases) for the entire data set. Most are exceeded only at other sites of known contamination by mining or mineral processing wastes. Extractable concentrations exceed the geometric means for soils of the western United States by the following factors: arsenic (4.1), boron (4.7) cobalt (2), nickel (2.7), selenium (1.7) and zinc (2.8). For all but selenium, these factors exceed one geometric deviation above the mean soil values.

Wagner Basin Research Natural Area

Climatic setting. The net annual precipitation balance for Wagner Basin (from the MAPS database) is -6 inches, ranking mid-range among sample sites of the Rocky Mountains. Mean monthly precipitation for the Gibson Reservoir climatic station shows a May-June peak. Total annual precipitation for the Gibson Reservoir station shows apparent periodicity, with the 3-year running average peaking every 4 to 7 years. The 3-year average remained near or below the long-term average throughout the 1980s and was near the long-term average in the early 1990s. In 1993 (the year of the DHES sampling) precipitation exceeded the long-term mean by nearly 5 inches.

Geologic setting. Wagner Basin is underlain by a faulted slice of Paleozoic sedimentary rocks including the Mississippian-aged Madison Group. The wetland is supported by a large spring discharging ground water from the Madison Group(?), or possibly from another carbonate formation in the Paleozoic section. Recharge to the ground-water system probably occurs locally within Wagner Basin. The location of the spring may be controlled by cavernous zones within carbonate aquifer(s) or, possibly, by thrust faults underlying basin. Discharging ground water flows across outwash and terrace gravel sediments fringing the wetland and to the Sun River. Surficial sediments include travertine and tufa deposits precipitated from the discharging ground water.

Hydrologic type. Wagner Basin receives perennial ground-water discharge from a discrete spring source and intermittent(?) surface runoff. Outflow occurs via an outlet stream and probably by seepage into terrace gravels fringing the wetland.

Basin characteristics. The catchment to wetland area ratio for Wagner Basin is relatively high compared to most other Rocky Mountain sample sites. Carbonate rocks underlie a large portion of the steep catchment and are inferred to receive ground-water recharge readily.

Water chemistry. Water sampled at the WET73 site was relatively dilute, slightly alkaline and calcium-sulfate/bicarbonate in composition. The calcium-sulfate character of this site is unusual among the unimpaired sample sites; the few other sites with similar proportions of major ion equivalents are in wetlands impacted by acid mine drainage or underlain by notably gypsiferous Colorado Group shales. Wagner Basin's water composition is believed to be influenced by dissolution of calcium sulfate evaporites (gypsum or anhydrite) within the carbonate aquifer(s) drained by the Wagner Basin springs. Mineral equilibria indicate slight over-saturation with carbonate phases and undersaturation with gypsum.

WET73 was among the minority of sites with reportable nitrate; the orthophosphate concentration ranked mid-range in comparison to

sites within this class, and the ammonium concentration was below reporting limits. The total organic carbon concentration was among the lowest for all sample sites.

Most trace element concentrations analyzed were below reporting limits. The iron concentration was comparatively low, and boron occurred at the reporting limit.

Chemical history. No other chemical data from this site are known.

Sediments. Extractable arsenic and copper concentrations ranked toward the bottom of the ranges shown for Rocky Mountain sites. Boron, iron, chromium, nickel and zinc were all relatively high within the site class, and were exceeded mainly at sample sites with known impacts from mining or mineral processing. The extractable zinc concentration exceeded the mean value for soils of the western United States by a factor of 1.4, and nickel and boron exceeded the regional mean soil concentrations by small factors.

Warhorse National Wildlife Refuge

Climatic setting. The net annual precipitation balance for Warhorse Lake (from the MAPS database) is -28 inches, placing Warhorse in the middle of the narrow range of evaporative intensity shown by sites of the unglaciated plains, and near the evaporative extreme of the range shown by the entire data set. Mean monthly precipitation for the Winnett climatic station shows a pronounced summer peak with a June maximum. Annual total precipitation for the Winnett station is not available for recent years; regionally, many stations experienced above-average precipitation in 1993 (the year of sampling) and near-average precipitation in 1992.

Geologic setting. Warhorse Lake and its natural catchment are underlain entirely by fine-grained sedimentary rocks of the Colorado Group. Colorado Group shales in the Warhorse area are described as bearing ubiquitous selenite (gypsum). The Warhorse basin appears to be structurally controlled, lying along the axis of a northwest-trending syncline. No description of surficial sediments in the immediate area is available; based on the underlying geology, surficial sediments are inferred to be mainly fine-grained, of low permeability and gypsiferous.

Hydrologic type. Warhorse Lake occupies a natural, structurally controlled basin augmented by impoundments and formerly supplied by water imports from Fords Creek, draining portions of the southern Judith Mountains. Water imports have not occurred for at least 10 years, and water supply to the lake is now derived only from the natural surface catchment. Warhorse Lake has presently unused outflow structure formerly used to control irrigation water supply.

Basin characteristics. The natural catchment of Warhorse Lake is relatively small, and the catchment to wetland area ratio is the lowest among sites of the unglaciated plains. Past water imports from the Fords Creek drainage (no longer practiced) effectively increased the contributing area many-fold. Information on water depth is not available. Under current management practices, the lake is reported to hold water during the autumn bird migration less than 50% of the time, and low basin gradients ensure a high degree of shoreline transience.

Water chemistry. At the time of sampling, Warhorse Lake contained slightly alkaline, "oligosaline" water of unusual calcium-sulfate composition. [Calcium is the proportionately highest cation but does not dominate the cation field, accounting for 42% of the cation equivalence.] Equilibrium calculations indicate near-equilibrium with carbonate phases and undersaturation with gypsum. The major-ion chemistry of Warhorse Lake is apparently influenced by the (reportedly) ubiquitous occurrence of selenite (gypsum) in local Colorado Group shales and derivative soils.

Warhorse Lake contained the second-highest nitrate concentration in the sample set, and the highest among sites of the unglaciated plains. The WET74 sample also contained significant ammonium. The orthophosphorous concentration was one of the lowest of the unglaciated plains, exceeding only non-lacustrine sites (Burns Creek and the Lavina DOT site.) The total phosphorous and total organic carbon concentrations also were relatively low in comparison to other sites in this classification. (The total phosphorous analysis was conducted on a different sample collected under different hydrologic conditions.)

Arsenic and boron concentrations were relatively low in comparison to other sites in this class. The chromium concentration reported ranks mid-range among the generally enriched nonglaciated plains sites, but still exceeds all sample sites in other ecoregions. The copper concentration reported is the highest in the sample set, exceeding western sites with impacts from mining and mineral processing.

Chemical history. No other data on the water chemistry of this site are known. The U.S. Fish and Wildlife Service reports no water quality problems or history of visible salinization during low-water conditions.

Sediments. The extractable iron concentration of the WET74 sediment sample was one of the highest in the data set, exceeded only by samples from sites with known impacts from mining and mineral processing. Extractable arsenic, copper, nickel and zinc concentrations were at or near the upper end of the ranges shown for sites in the unglaciated plains. Chromium and vanadium concentrations ranked mid-range or lower within the site class. WET74 was one of the few plains sites without a reportable concentration of extractable boron in the sediment sample.

Extractable arsenic, copper, nickel and zinc concentrations exceed the geometric mean values for soils of the western United States by factors of 1.5, 2.1, 2.3 and 1.9 respectively.

Warm Springs Ducks Unlimited Pond

Climatic setting. The net annual precipitation balance for the Warm Springs DU pond (from the MAPS database) is -20 inches, placing the site mid-range in evaporative intensity when compared to other sites of the intermontane basins. Mean monthly precipitation for the Anaconda climatic station shows a broad summertime maximum. The 3-year running average of annual precipitation was below the long-term average from 1986 through 1992. In 1993 (the year prior to sampling), precipitation exceeded the long-term average by about 8 inches. Regionally, precipitation totals in 1994 were below average.

Geologic setting. The WET75 site is underlain by alluvial fan sediments deposited by Warm Springs Creek. Fan sediments are relatively thin (a few tens of feet) and are underlain by valley-fill sediments of Tertiary age. Recent surficial sediments in the Warm Springs Creek area are pervasively contaminated with mineral processing wastes. Shallow water table depths and ground-water discharge from shallow flow systems characterize the lower Warm Springs Creek fan near the WET75 site. Discharge from a deep-circulating geothermal flow system also occurs nearby, supporting the local hot springs.

Hydrologic type. The Ducks Unlimited pond is a depression of unknown origin in the Warm Springs fan sediments, seasonally(?) intersecting the water table surface. The wetland is augmented by water imports diverted from Warm Springs Creek. The water body does not appear to have a surface outlet but is inferred to discharge to the shallow ground-water system under at least some conditions.

Basin characteristics. The DU pond has a minimal natural surface catchment but is believed to receive ground-water recharged over a broad area, as well as diverted Warm Springs Creek water. The depth of the small water body is uncertain and has been subject to modification to meet wildlife habitat objectives.

Water chemistry. The DU pond contains dilute calcium-sulfate/bicarbonate water with moderately low alkalinity and basic pH. Mineral equilibria indicate slight oversaturation with carbonate phases. Ammonium, nitrate, and phosphorous concentrations rank mid-range with respect to sample sites in the intermontane valleys. (Phosphorous concentrations are low, however, in comparison to other sites lacking surface water outflow.) The total organic carbon concentration was among the lowest sampled.

Trace element concentrations in the water column were generally low. Iron and arsenic concentrations ranked toward the lower end of the ranges shown for western sites. The copper and aluminum concentrations ranked mid-range within the site class, and most other trace elements analyzed occurred at concentrations below

reporting limits.

Chemical history. No previous chemical data from this site are known.

Sediments. Extractable concentrations of arsenic, chromium, copper, nickel, vanadium and zinc rank near the upper end of the ranges shown for western sites, reflecting contamination of surficial sediments with mineral processing waste. WET75 was also one of the few sites with a reportable mercury concentration (at the reporting limit).

The extractable arsenic, copper, and zinc concentrations exceed the geometric mean soil concentrations for the western United States by factors of 4, 4.8 and 2.4 respectively. Other trace element concentrations are near or below the regional means.

Warm Springs Pond #1

Climatic setting. The net annual precipitation balance for the Warm Springs ponds (from the MAPS database) is -20 inches, placing these sites mid-range in evaporative intensity when compared to other sites of the intermontane basins. Mean monthly precipitation for the Anaconda climatic station shows a broad summertime maximum. The 3-year running average of annual precipitation was below the long-term average from 1986 through 1992. In 1993 (the year prior to sampling), precipitation exceeded the long-term average by about 8 inches. Regionally, precipitation totals in 1994 were below average.

Geologic setting. The Warm Springs Ponds are underlain by mill tailings, heavily contaminated historic stream sediments and chemical precipitates deposited by Silver Bow Creek. The ponds are constructed over earlier alluvial deposits of Silver Bow (and Warm Springs?) Creek in the neighborhood of 20 feet in thickness, which in turn overlies Tertiary-aged sediments up to several hundred feet thick.

Hydrologic type. The Warm Springs Ponds are a complex of artificial impoundments constructed and managed for the purpose of capturing tailings and treating contaminated streams (Silver Bow Creek, Mill Creek and Willow Creek) draining the Butte and Anaconda areas. Water inflows, outflows, routing and chemistry are manipulated in order to meet water treatment objectives. The design and operation of the ponds have been altered significantly in the past 5 years (see below).

Basin characteristics. Silver Bow Creek and most of the flow of Mill and Willow Creeks carried by the Mill-Willow Bypass enters Pond #3 near the WET78 sample site, where continuous pH adjustment by lime injection occurs. Up to 300 cfs is discharged from Pond #3 by two outflow structures into Pond #2; Pond #3 inflow in excess of 300 cfs is routed back into the Mill-Willow Bypass and out of the pond system. Outflow from Pond #2 discharges to the lowermost channel of the Mill-Willow Bypass and on to the Clark Fork River. No water is intentionally routed to Pond #1, the oldest cell in the pond complex. Seepage from Pond #2 to the downgradient Pond #1 occurs, joining precipitation falling on the Pond #1 surface. Ground-water outflow from Pond #1 to the alluvium downgradient also occurs.

The operation of Pond #2 changed during the 5 years prior to the DHES sampling in order to improve effluent water quality. The stage of Pond #2 has been raised in order to permanently flood areas of tailings which in the past were subject to fluctuating water levels and variable redox conditions. Increased head in Pond #2 appears to have increased ground-water outflow to Pond #1. Prior to raising water levels in Pond #2, the surface was treated with lime to immobilize metals.

The western portion of Pond #1 has been treated and capped and the process of establishing vegetation on the capped surface begun. Future water levels in the eastern portion of Pond #1 (including the WET76 site) may be manipulated to retain reducing conditions in wetland sediments.

Water chemistry. At the time of sampling, Pond #1 contained "oligosaline" calcium-sulfate water of low alkalinity and moderately basic pH. Equilibrium calculations indicate moderate oversaturation with carbonate minerals. Nitrogen concentrations (nitrate and ammonium) were below reporting limits. Phosphorous (total and orthophosphate) and total organic carbon concentrations ranked mid-range among sites of the intermontane valleys.

Water-column concentrations of boron, copper, iron, lead and zinc ranked near the upper end of the ranges shown for intermontane sites. The arsenic concentration ranked mid-range, and most other trace elements occurred in concentrations below reporting limits.

Chemical history. Although DHES documents (see bibliography) identify this as a sampling site, no other water chemistry data were recovered. See discussion above for general history of water chemistry factors.

Sediments. Sediments collected at WET76 show the highest extractable concentrations in the sample set for many trace elements, and in general may reflect the most heavily contaminated conditions of the mining-impacted sites. Extractable concentrations of arsenic, chromium, copper, manganese, selenium, and mercury ranked at the top of the range shown by the data set; boron, iron, lead, vanadium, and zinc concentrations rank near the top also. These elements exceed geometric mean values for soils of the western United States by factors ranging from 1.5 to more than 100.

Warm Springs Pond #2

Climatic setting. The net annual precipitation balance for the Warm Springs ponds (from the MAPS database) is -20 inches, placing these sites mid-range in evaporative intensity when compared to other sites of the intermontane basins. Mean monthly precipitation for the Anaconda climatic station shows a broad summertime maximum. The 3-year running average of annual precipitation was below the long-term average from 1986 through 1992. In 1993 (the year prior to sampling), precipitation exceeded the long-term average by about 8 inches. Regionally, precipitation totals in 1994 were below average.

Geologic setting. The Warm Springs Ponds are underlain by mill tailings, heavily contaminated historic stream sediments and chemical precipitates deposited by Silver Bow Creek. The ponds are constructed over earlier alluvial deposits of Silver Bow (and Warm Springs?) Creek in the neighborhood of 20 feet in thickness, which in turn overlie Tertiary-aged sediments up to several hundred feet thick.

Hydrologic type. The Warm Springs Ponds are a complex of artificial impoundments constructed and managed for the purpose of capturing tailings and treating contaminated streams (Silver Bow Creek, Mill Creek and Willow Creek) draining the Butte and Anaconda areas. Water inflows, outflows, routing and chemistry are manipulated in order to meet water treatment objectives. The design and operation of the ponds have been altered significantly in the past 5 years (see below).

Basin characteristics. Silver Bow Creek and most of the flow of Mill and Willow Creeks carried by the Mill-Willow Bypass enters Pond #3 near the WET78 sample site, where continuous pH adjustment by lime injection occurs. Up to 300 cfs is discharged from Pond #3 by two outflow structures into Pond #2; Pond #3 inflow in excess of 300 cfs is routed back into the Mill-Willow Bypass and out of the pond system. Outflow from Pond #2 discharges to the lowermost channel of the Mill-Willow Bypass and on to the Clark Fork River. No water is intentionally routed to Pond #1, the oldest cell in the pond complex. Seepage from Pond #2 to the downgradient Pond #1 occurs, joining precipitation falling on the Pond #1 surface. Ground-water outflow from Pond #1 to the alluvium downgradient also occurs.

The operation of Pond #2 changed during the 5 years prior to the DHES sampling in order to improve effluent water quality. The stage of Pond #2 has been raised in order to permanently flood areas of tailings which in the past were subject to fluctuating water levels and variable redox conditions. Increased head in Pond #2 appears to have increased ground-water outflow to Pond #1. Prior to raising water levels in Pond #2, the surface was treated with lime to immobilize metals.

The western portion of Pond #1 has been treated and capped and the process of establishing vegetation on the capped surface begun. Future water levels in the eastern portion of Pond #1 may be manipulated to retain reducing conditions in wetland sediments.

Water chemistry. At the time of sampling, the WET77 site exhibited dilute, moderately alkaline calcium-bicarbonate/sulfate water. Dissolved solids, pH and proportional sulfate concentrations were lower than at WET76. Mineral equilibria indicate slight oversaturation with calcium carbonate phases. In contrast to WET77, nitrate and ammonium concentrations were comparatively high. Phosphorous concentrations (total and orthophosphorous) ranked mid-range with respect to sample sites of the intermontane valleys, and the total organic carbon concentration was near the low end of the range for the site class.

Water-column concentrations of arsenic, iron, copper and zinc rank mid-range among sites of the intermontane valleys and are of similar magnitude to WET76 concentrations. Most other trace element concentrations were below reporting limits.

Chemical history. Seasonal time-series water chemistry data are presented in DHES documents referenced in the site bibliography.

Sediments. Extractable calcium concentrations in the WET77 sediment sample are high, reflecting liming of the pond saturation of the water column with calcium carbonate. Extractable concentrations of trace elements are generally much lower than at either WET76 or WET78. Arsenic, copper and zinc concentrations exceed geometric means of soils concentrations in the western United States by factors of 2.7, 1.4 and 1.7 respectively.

Warm Springs Pond #3

Climatic setting. The net annual precipitation balance for the Warm Springs ponds (from the MAPS database) is -20 inches, placing these sites mid-range in evaporative intensity when compared to other sites of the intermontane basins. Mean monthly precipitation for the Anaconda climatic station shows a broad summertime maximum. The 3-year running average of annual precipitation was below the long-term average from 1986 through 1992. In 1993 (the year prior to sampling), precipitation exceeded the long-term average by about 8 inches. Regionally, precipitation totals in 1994 were below average.

Geologic setting. The Warm Springs Ponds are underlain by mill tailings, heavily contaminated historic stream sediments and chemical precipitates deposited by Silver Bow Creek. The ponds are constructed over earlier alluvial deposits of Silver Bow (and Warm Springs?) Creek in the neighborhood of 20 feet in thickness, which in turn overlies Tertiary-aged sediments up to several hundred feet thick.

Hydrologic type. The Warm Springs Ponds are a complex of artificial impoundments constructed and managed for the purpose of capturing tailings and treating contaminated streams (Silver Bow Creek, Mill Creek and Willow Creek) draining the Butte and Anaconda areas. Water inflows, outflows, routing and chemistry are manipulated in order to meet water treatment objectives. The design and operation of the ponds have been altered significantly in the past 5 years (see below).

Basin characteristics. Silver Bow Creek and most of the flow of Mill and Willow Creeks carried by the Mill-Willow Bypass enters Pond #3 near the WET78 sample site, where continuous pH adjustment by lime injection occurs. Up to 300 cfs is discharged from Pond #3 by two outflow structures into Pond #2; Pond #3 inflow in excess of 300 cfs is routed back into the Mill-Willow Bypass and out of the pond system. Outflow from Pond #2 discharges to the lowermost channel of the Mill-Willow Bypass and on to the Clark Fork River. No water is intentionally routed to Pond #1, the oldest cell in the pond complex. Seepage from Pond #2 to the downgradient Pond #1 occurs, joining precipitation falling on the Pond #1 surface. Ground-water outflow from Pond #1 to the alluvium downgradient also occurs.

The operation of Pond #2 changed during the 5 years prior to the DHES sampling in order to improve effluent water quality. The stage of Pond #2 has been raised in order to permanently flood areas of tailings which in the past were subject to fluctuating water levels and variable redox conditions. Increased head in Pond #2 appears to have increased ground-water outflow to Pond #1. Prior to raising water levels in Pond #2, the surface was treated with lime to immobilize metals.

The western portion of Pond #1 has been treated and capped and the process of establishing vegetation on the capped surface begun. Future water levels in the eastern portion of Pond #1 may be manipulated to retain reducing conditions in wetland sediments.

Water chemistry. At the time of sampling, Pond #3 at WET78 exhibited relatively dilute, moderately alkaline calcium-bicarbonate chemistry. Mineral equilibria indicate near-saturation with carbonate phases. Nitrogen and phosphorous concentrations rank mid-range in comparison to other sites of the intermontane valleys. The total organic carbon concentration was low in comparison to other sites in this class. Water-column concentrations of arsenic, copper, cadmium, iron and zinc rank at or near the upper end of the ranges shown by intermontane valley sites, and are generally higher than those at the other two Warm Springs Ponds sites. Other trace element concentrations were below reporting limits.

Chemical history. No other chemical data from this site are known. Data from a site approximately 1 mile from WET78 include seasonal time-series water quality analyses. See the site bibliography for references.

Sediments. Sediments from WET78 display highly elevated concentrations of trace elements. Extractable concentrations of arsenic, copper, lead, mercury, selenium, and zinc near the top of the ranges shown by sites of the intermontane valleys, and for most elements are exceeded only at other sites contaminated with mining and mineral processing wastes. Extractable concentrations of all of these elements (and boron) exceed the geometric mean values for soils of the western United States by up to factors of 50.

White Lake

Climatic setting. The net annual precipitation balance for White Lake derived from the MAPS database is -23 inches, toward the less evaporative end for sites in this class. Based on analyses of evaporation pan data, this is a considerable underestimate White Lake's water deficit, and points out the need to view the MAPS estimates only as relative indicators of net site precipitation. Mean monthly precipitation for the Medicine Lake climatic station shows a pronounced June maximum. Annual totals for this station show apparent periodicity with a 5 to 7 year cycle. Throughout the 1980s, the 3-year running average remained below (often well below) the long-term average, recovering in the early 1990s. In 1993 (the year before sampling) precipitation exceeded the long-term average by more than 1 inch.

Geologic setting. White Lake occupies an ice-block depression (kettle) on the margin of the late Pleistocene outwash sand and gravel forming the Clear Lake aquifer. Surficial sediments within the lake basin are dominated by authigenic sulfate minerals precipitated from in-flowing ground water and fine-grained glaciolacustrine sediments contrasting with the permeable sand and gravel of the Brush Lake basin. Glacial sediments are underlain at depth by the early Tertiary Fort Union Formation.

Hydrologic type. White Lake is an ephemeral saline playa which receives in-flowing ground water (depleted in calcium through carbonate precipitation in upgradient Brush Lake) and has restricted ground-water outflow. White Lake lacks significant surface water inflow or outflow.

Basin characteristics. The shallow White Lake depression has a minimal surface catchment beyond the playa surface; the lake's water and solute budgets contrast with those of adjacent Brush Lake due to distinct aquifer permeabilities, different lake geometries and different influent water chemistry. The resulting lake water chemistries are markedly different but genetically related as components of a serial system of ground-water supported lakes which responds to variations in aquifer head with changes in lake area, volume and water chemistry.

Water chemistry. White Lake contains highly alkaline "hypersaline" sodium sulfate brine with very high ammonium concentration and total organic carbon concentrations and exceptionally high phosphorous concentration. Due to depletion through carbonate precipitation in Brush Lake, the influent calcium concentration in White Lake is very low and authigenic sedimentation is dominated by mirabilite ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$); mineral equilibria indicate slight undersaturation with respect to mirabilite at the time of the DHES sampling.

The concentrated White Lake brine exhibited the highest arsenic and second-highest boron concentrations of the sample set. The zinc

and iron concentrations were also high, with most higher concentrations reported from sites of known contamination with mining and mineral processing waste. Most other trace element concentrations were below reporting limits.

Chemical history. Previous chemical data from the White Lake basin were collected on shallow ground-water samples drawn from beneath the playa surface or from peripheral ponds known as East and West White Lakes, which exhibit much more dilute water chemistry. The shallow ground-water samples (collected in 1990 at a time of little or no surface water in the playa) were more concentrated than the WET79 sample; density gradients may maintain salinity contrasts between the shallow ground water brine and surface water during periods of inundation. Generally, White Lake probably exhibits substantial salinity variation but remains hypersaline in character.

Sediments. Authigenic sediments in the White Lake basin are dominated by sodium sulfate salts not represented in the DHES sediment analysis. Relatively high calcium and magnesium concentrations may reflect both detrital sediments and minor authigenic carbonate precipitation.

The extractable arsenic concentration was the highest for any sample site not impacted by mining wastes, and exceeded all other Great Plains sites by a wide margin. The boron concentration reported also ranks relatively high. Extractable iron, vanadium and zinc concentrations were relatively low, and most other trace element concentrations were below reporting limits. Extractable arsenic and boron concentrations exceeded geometric mean soil concentrations for the western United States by factors of 13.9 and 2.4, respectively.

Yellowstone River Oxbow

Climatic setting. The net annual precipitation balance for WET80 (from the MAPS database) is -30 inches, placing it at the more intensely evaporative extreme of the data set. Mean monthly precipitation for the Miles City climatic station shows a pronounced June maximum. Annual total precipitation was below the long-term average most years during the 1980s, while precipitation in the 1991-1993 period was at or above the long-term average. Water supply to the WET80 wetland is, however, probably tied closely to the stage of the Yellowstone River, which is influenced by precipitation and other climatic conditions throughout the basin.

Geologic setting. The WET80 site occupies an abandoned side channel of the Yellowstone River, developed along the edge of the modern floodplain and just below the edge of the older alluvial terrace underlying most of Miles City. The adjacent and underlying(?) bedrock is the Tullock member of the early Tertiary-aged Fort Union Formation. The alluvium is described as relatively coarse-grained and permeable; water table elevations are shallow, and are apparently intersected by the old channel swale containing the wetland. Geologic structures to the east and west generate pressure head in the Fort Union and underlying Hell Creek aquifers. Flowing wells (and by inference, discharge to the shallow alluvial aquifer system) occur in the vicinity of Miles City.

Hydrologic type. The Yellowstone River "oxbow" (sic) occupies a modified natural channel originating near the confluence of the Yellowstone and Tongue Rivers and passing through Miles City before rejoining the Yellowstone channel. The channel appears to intersect the water table of the alluvial aquifer in places. The wetland receives intermittent surface water inflow and, probably, ground-water discharge from the Yellowstone River alluvium. Outflow occurs via a high-water channel to the Yellowstone River. Rates of flux through the wetland probably depend on the stage of the Yellowstone and Tongue Rivers and on related water levels in the alluvial aquifer underlying the floodplain.

Basin characteristics. WET80 has a small local surface catchment heavily modified by urban activities and structures. Ground water inferred to support the wetland is probably recharged in part by the mainstem Yellowstone River. The depth and volume of the wetland water body and the frequency of surface inflow and outflow are not known.

The WET80 site is the only one of the sample sites where urban land uses dominate the wetland catchment.

Water chemistry. At the time of sampling, the WET80 site displayed near-neutral, "oligosaline" sodium-sulfate/carbonate water with a depressed dissolved oxygen concentration and relatively high total

alkalinity. Equilibrium calculations indicate moderate oversaturation with respect to carbonate minerals. Depressed dissolved oxygen and apparent non-equilibrium of pH, carbonate and bicarbonate with surface conditions may reflect ground-water discharge to the WET80 site. The high sodium concentration (64% of the cation load in meq/l) may reflect some input from deeper aquifers to the alluvial gravel aquifer.

The nitrate concentration at WET80 was below the reporting limit; the ammonium concentration was among the highest for sample sites from the unglaciated plains province. Phosphorous concentrations were also relatively high, exceeded in the region mainly by closed-basin sites. The total organic carbon concentration ranked mid-range among sites of the plains.

Arsenic, boron, and copper concentrations ranked mid-range or lower in comparison to the site class, while iron and lead concentrations ranked relatively high. Most other trace elements analyzed were below reporting limits.

Chemical history. No previous data from this site are known.

Sediments. Most extractable trace element concentrations are relatively low in comparison to other sites of the unglaciated plains. Extractable lead and zinc concentrations, however, rank relatively high, and in the case of lead are exceeded almost entirely by sites with known impacts from mining or mineral processing. Boron, lead and zinc concentrations exceed geometric mean concentrations for soils of the western United States by factors of 2.3, 2.4 and 1.5, respectively. Other trace element concentrations reported are below regional geometric mean soil values.

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Appendix C



Geologic, Geomorphic and Chemical Characteristics of Wetlands Selected for Use in Biocriteria Development by the Montana Department of Environmental Quality

by

Mark D. Shapley
Montana Natural Heritage Program
1515 East 6th Avenue
Helena, MT 59620

for the

Montana Department of Environmental Quality
Water Quality Division

December, 1995

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Appendix C

Annotated Geologic and Hydrologic Bibliography of the DEQ Wetland Characterization Sites

ANNOTATED BIBLIOGRAPHY OF WETLAND SITE GEOLOGY

Alkali Lake.

Bibliographic Source: Geoindex lat-long search

Author: Coffin, D.L., A. Brietkrietz and R.G. McMurtry

Title: Surficial geology and water resources of the Tobacco and Stillwater River valleys, northwestern Montana

Series: Montana Bureau of Mines and Geology Bulletin 81

Date: 1971

Geologic mapping at scale of approx 1:84500 shows Alkali and Thirsty lakes underlain by Quaternary alluvium, but surrounded closely by till of unspecified age (presumably late Wisconsin). Most of catchment is probably underlain by till. Alluvium is likely thin, but no well records shown. No indications of till thickness or of underlying stratigraphy in Alkali Lake area. The bedrock outcrops are shown as Precambrian undivided. No quantitative descriptions of till source composition.

Water quality data include two conductivity measurements of 1230 (June 1968) and 1300 (October 1968) microsiemens/cm, and lab analysis from Thirsty Lake. Thirsty lake was several times more saline, much more sodic and depleted in sulfate relative to 1993 Alkali Lake.

Includes generalizations about ground-water quality in study area, no close by analyses but several from adjoining townships.

Bibliographic Source: Geoindex lat-long search

Author: Harrison, J.E., E.R. Cressman and J.W. Whipple

Title: Preliminary geologic and structure maps of part of the Kalispell 1 X 2 degree quadrangle, Montana

Series: USGS Open-file report 83-502

Date: 1983

Line map of bedrock geology at 1:250,000 scale showing the distribution of Belt series metasediments and structural relationships. Surficial sediments are only broadly differentiated

at this scale.

Bandy Reservoir

Bibliographic source: None - personal collection

Author: Dea, Peter

Title: Glacial geology of the Ovando Valley, Powell County, Montana

Series: University of Montana M.S. thesis in geology

Date: 1981

Detailed surficial geologic mapping at approximately 1:40,000 scale shows the Bandy Reservoir site underlain by glacial till deposited by the late Pleistocene Monture Creek advance. Description of the Monture till lithology indicates that matrix grain size is variable from sand to clay, and that limestone constitutes a significant minority of the larger clast sizes. Clast lithologies described (including limestone) reflect Proterozoic (Belt) formations exposed in the Monture Creek drainage.

Monture glacial deposits are interpreted as post-dating and truncating deposits of the Clearwater advance, originating from the Clearwater drainage to the northwest. Bandy Reservoir is near the western margin of mapped Monture Creek deposits, and may overlie Clearwater deposits (including possibly outwash) at depth. No stratigraphic information for this area is provided.

Bibliographic source: Geoindex lat-long search.

Author: Mudge, M.R., R.L. Earhart, J.W. Whipple and J.E. Harrison

Title: Geologic and structure map of the Choteau 1 degree X 2 degree quadrangle.

Series: U.S. geological Survey Miscellaneous Investigations Series Map I-1300

Date: 1982

Regional compilation of bedrock geology at 1:250,000 scale shows Monture Creek and the Clearwater Valley (both drainages may be contributing areas to glacial deposition at this site) underlain by outcrops of all Proterozoic Y (Belt) formations from the Helena Formation through the Bonner Quartzite. In addition, Monture Creek outcrops include both older (Empire and Spokane Formations) and younger (McNamara Formation) Belt units. Both drainages include large areas of the dominantly carbonate Helena Formation.

Beaver Creek

Bibliographic source: Geoindex lat-long search

Author: Witkind, I.J and W.M. Weber

Title: Reconnaissance geologic map of the Big Fork - Avon Environmental Study Area, Flathead, Lake, Lewis and Clark, Missoula and Powell Counties, Montana.

Series: USGS Miscellaneous Investigations Series Map I-1380

Date: 1982

Geologic mapping at 1:125,000 scale emphasizing surficial deposits shows the sampling site to be underlain by late Pleistocene till of the Placid Creek glacier. Till texture is described as coarse, with abundant cobbles and boulders in typically sandy or silty matrix. Soil drainage described as poor. Nearby Pre-Quaternary outcrops are mapped as undifferentiated Proterozoic Y (Belt). WNW trending normal faults (concealed beneath surficial deposits) traverse the area, and are shown as bracketing the wetland site. This document provides no direct hydrologic or hydrogeologic information.

Bibliographic source: Geoindex lat-long search.

Author: Mudge, M.R., R.L. Earhart, J.W. Whipple and J.E. Harrison.

Title: Geologic and structure map of the Choteau 1 X 2 quadrangle, western Montana.

Series: USGS Miscellaneous Investigations Series Map I-1300.

Date: 1982

Regional compilation of bedrock geology shows the pre-Quaternary

outcrops in the immediate area of the wetland to be composed of the Mount Shields Formation and Bonner Quartzite of Proterozoic Y (Belt) age. The Mount Shields Formation is dominantly argillitic and quartzitic, along with other noncalcareous lithologies. The Bonner Quartzite is dominantly feldspathic.

Upgradient areas presumed to have contributed sediment to the Placid Creek glacier include outcrops of the underlying Shephard and Mount Shields Formations, described as having minor limestone components but consisting primarily of argillite, siltite and minor quartzite. The contributing area does not appear to include outcrops of Helena Formation or other dominantly carbonate formations.

Bent Flat

Bibliographic source: Geoindex lat-long search

Author: Mudge, M.R. and R.L. Earhart

Title: Geologic map of the Bob Marshall and Great Bear Wildernesses and adjacent study areas, northwestern Montana.

Series: USGS Miscellaneous Investigations Series Map I-2181

Date: 1991

Regional mapping at 1:125,000 scale shows the Bent Flat area as undifferentiated glacial material and the ridges within the drainage as undifferentiated Cambrian (heavily carbonate lithologic descriptions) and Belt (Sheppard and Mount Shields Formations). Structures include a buried fault transecting Bent Flat, striking north-northwest. This is the most legible map compilation for the area.

Bibliographic source: Geoindex lat-long search

Author: Mudge, M.R. and R.L. Earhart

Title: Bedrock geologic map of part of the Northern Disturbed Belt, Lewis and Clark, Teton, Pondera, Glacier, Flathead, Cascade and Powell Counties, Montana

Series: U.S. Geological Survey Miscellaneous Investigations Series Map I-1375

Date: 1983

Regional bedrock mapping at 1:125000 scale is probably from the

same base as Mudge and Earhart (1991) cited above. Bedrock mapped beneath Bent Flat glacial cover (not shown) is a downdropped block of Devonian undifferentiated, ridges to the east are shown as Cambrian undifferentiated, with Bent Mountain relatively uplifted Belt (Mount Shields Formation). Both the Cambrian and Devonian sections are described as heavy in carbonates, with the Devonian sequence including evaporite-solution breccias.

Bibliographic source: Geoindex lat-long search

Author: Johns, W.M.

Title: Geology and mineral deposits of Lincoln and Flathead Counties, Montana

Series: Montana Bureau of Mines and Geology Bulletin 79

Date: 1970

Regional mapping at approximate scale of 1:125,000 shows Bent Flat underlain by undifferentiated glacial material. Bedrock mapping differs from later interpretations (Mudge and others) in showing lower slopes of ridges draining to Bent Flat as undifferentiated Devonian rather than Cambrian. Bent Mountain ridgetop is shown as undifferentiated Missoula Group (Belt). The Bent Flat buried fault of Mudge and Erhart is not shown.

Benton Lake.

Bibliographic source: Geoindex lat-long search

Author: Colton, R.B., R.W. Lemke and R.M. Lindvall

Title: Glacial map of Montana east of the Rocky Mountains

Series: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-327

Date: 1961

Regional mapping of glacial surface features at 1:500,000 scale shows Benton Lake just within the margin of maximum glacial advance, notwithstanding the glaciolacustrine sediments described by others as underlying the lake basin. This interpretation suggests that the surficial stratigraphy may include till as well as lacustrine sediments.

Bibliographic source: GeoIndex lat-long search

Author: Lemke, R.W.

Title: Geologic map of the Great Falls Quadrangle, Montana.

Series: USGS Geologic Quadrangle Map GQ-1414

Date: 1977

Map at scale of 1:62500 shows most of Benton Lake underlain by glaciolacustrine sediments of glacial Lake Great Falls. These are described as being as much as 100 feet in thickness in Benton Lake area, and in Benton Lake area consist predominantly of a plastic clay facies. Northern end of the lake is underlain by undifferentiated alluvium and colluvium.

The NW trending axis of the Sweetgrass Arch passes southwest of Benton Lake, elevating a large area of the Bootlegger member of the Blackleaf Formation in the southern part of the lake catchment. Interbedded sandstone, siltstone and shale with several bentonite beds.

North of the lake, mapping shows till cover (described as up to 70 feet thick) overlying the Marias River Shale. Three of the four members of the shale are described as calcareous at least occasionally, minor siltstone and sandstone interbeds within the Ferdig and Floweree members.

No hydrologic information. Uppermost predictable aquifer is probably the Kootenai Formation, underlying Blackleaf Fmn.

Bibliographic source: U.S.Geological Survey office inquiry

Author: Knapton, J.R., W.E. Jones and J.W. Sutphin

Title: Reconnaissance investigation of water quality, bottom sediment and biota associated with irrigation drainage in the Sun River area, west-central Montana

Series: U.S. Geological Survey Water-Resource Investigations report 87-4244

Date: 1987

This study included limited ground-water sampling in the Greenfields Bench gravels, and water quality, bottom sediment and biotic sampling of all of the Benton Lake pools. Ground water quality analyses include a high-selenium seep near Benton Lake.

Statistical summaries of the data and a comprehensive bibliography are included.

Bibliographic source: Inquiry to U.S. Geological Survey

Author: Lambing, J.H., D.A. Nimick, J.R. Knapton and D.U. Palwski

Title: Physical, chemical and biological data for detailed study of the Sun River Irrigation Project, Freezout Lake Wildlife Management Area, and Benton Lake National Wildlife Refuge, west-central Montana, 1990-92, with selected data for 1987-89.

Series: U.S. Geological Survey Open-file report 94-120

Date: 1994

This document contains descriptions of the data collection programs initiated in and around Freezout and Benton Lakes in 1990, and tabulations of soil, surface water and ground water, lake sediment and bioassay data. Interpretation of these data is pending.

The data assembled include a continuous record of specific conductance of the Lake Creek inflow, water quality and bottom sediment analyses from pools #1, 2, 3 and 5, and groundwater analyses and drill-hole descriptions from the vicinity of a saline seep along the west shore, and additional ground water analyses from water-supply wells.

Big Lake

Bibliographic source: Geoindex lat-long search

Author: Ellis, M.S.

Title: Geologic map of the Powder River basin and surrounding area, Wyoming, Montana, South Dakota, North Dakota and Nebraska

Series: USGS Miscellaneous Field Studies Map MF-2095

Date: 1989

Map scale (1:500,000) not particularly useful. Sampling location is at the extreme western limit of map coverage. The map is a compilation showing regional distribution of bedrock geologic units

(lots of Bearpaw, Judith River and Eagle Formations) and regional structure. These are the only usefulness of this map.

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index

Author: Feltis, R.D.

Title: Hydrogeologic map of the Billings 1 degree X 2 degree quadrangle and vicinity, Montana

Series: MBMG Hydrogeologic Map 9 A-F

Date: 1988

Regional compilation at 1:250,000 scale emphasizes outcrop distribution and structural contouring, with Stiff diagrams of water chemistry for different aquifers found within the quadrangle. The Big Lake topographic basin is shown to be along the eastern limb of the Lake Basin anticline, a hydrocarbon trap penetrated by numerous oil and/or gas wells. The Lake Basin anticline is shown intersecting the Lake Basin Fault Zone in the vicinity of Halfbreed Lake.

Mapping shows the Big Lake area to underlain by rocks above the base of the Eagle Sandstone (Map 9E) and below the base of the Lennep Sandstone (Map 9F). Surface of Bearpaw Shale is implied, but not shown as outcrop. (Bearpaw Formation is shown by Ross, Andrews and Witkind (1955) at 1:500,000 scale.)

Stiff diagrams (Map 9E) indicate nearby analyses of the Virgelle sandstone (of the Eagle Formation), the uppermost consolidated aquifer in the area, exceed 2000 mg/l TDS and are sodium chloride or sodium bicarbonate/chloride in composition. (The analyses displayed probably reflect mainly oilfield waters.)

Big Sandy DOT Mitigation Wetland

Bibliographic Source: Geoindex lat-long search

Author: Lindvall, R.M.

Title: Geology of the Big Sandy Quadrangle, Montana

Series: USGS Miscellaneous Geologic Investigations Map I-130

Date: 1956

Geologic mapping at 1:62,500 emphasizing surficial geology and glacial features. Sampling site is shown very near the contact of alluvium/colluvium material filling the preglacial Missouri channel and "ground moraine". Ground moraine in the quad is described as compact and of low permeability. The till is shown as 60 feet thick near Big Sandy.

Nearby wells shown, indicating the fill within the channel is on the order of 100 feet thick. Stratigraphic relationship between the till and the alluvium/colluvium is unclear from the map.

Bedrock formations underlying the surficial deposits are the Upper Cretaceous Claggett Shale (sandy in the upper 150 feet) and the overlying Judith River Formation. The immediate area of the site is underlain by the Claggett.

The map includes a qualitative summary of the engineering characteristics of the map units. Permeabilities of the undifferentiated alluvium/colluvium are described as highly variable. Permeability of the till and Claggett are very low. The site is near the edge of the sheet, so the distribution of map units in most of the upgradient Big Sandy Creek basin is not shown, although Cretaceous bedrock units must dominate the basin.

Bibliographic source: Geoindex lat-long search

Author: Swenson, F.A.

Title: Geology and ground-water resources of the lower Marias irrigation project, Montana.

Series: USGS Water-Supply Paper 1460-B

Date: 1957

Geologic mapping at a scale of 1:94500 emphasizes surficial geology. The general area of the site is mapped as paludal, described as plastic clay and silt. This map unit covers several sections in this part of the pre-glacial Missouri channel. The valley margin, possibly underlying the site, is mapped as a kame terrace with unclear(?) stratigraphic relationship to the paludal silts.

Isopach map included in the text shows the total thickness of unconsolidated deposits exceeding 200 feet near Boxelder, without coverage of Big Sandy. Interesting observations about the retention and infiltration of water entering the Lonesome Lake Basin. Page 51 includes table showing 6 years of monthly discharge data from Big Sandy Creek 2.5 miles SE of Big Sandy (pre-irrigation project - did the irrigation intended ever happen??).

Page 63 includes a description of the kame terrace and esker deposits near the sampling site, some of which are well sorted and mined for gravel. [Kame terrace likely elevated above water table??] Page 65 includes a description of the paludal deposits, characterized as "extremely fine-grained" and unlikely to yield much water to wells. Paludal deposits are also described "relatively thin", but no values are given. Description of conditions in 1946 indicate that high water table and capillarity caused visible surficial salt concentrations near the sampling site.

Water quality analyses from Quaternary aquifers in the pre-glacial Missouri channel (copied) contain dissolved solids up to 2600 mg/l. Na:Ca+Mg ratios are high in the higher-TDS water of the Missouri channel, lower in alluvial fan deposits.

A shallow observation well was maintained within the sample site quarter-section (28-13-5dd), with bimonthly measurements from 1946-1953, with water levels ranging from about 4.5 to >11.5 feet during the period of record. Spring peaks, winter minimum levels.

Bibliographic source: Geoindex lat-long search

Author: Pierce, W.G. and C.B. Hunt

Title: Geology and mineral resources of north-central Choteau, western Hill and eastern Liberty Counties, Montana.

Series: USGS Bulletin 847-F

Date: 1937

Mapping at a scale of about 1:125,000 with Big Sandy at the extreme eastern edge of the coverage. Generalized bedrock only, with no surficial geology shown. This document is of historical interest only, adds nothing to useful to information about surficial materials or hydrology.

Black Coulee

Bibliographic source: Geoindex lat-long search

Author: Zimmerman, E.A.

Title: Preliminary report on the geology and ground-water

resources of northeastern Blaine County, Montana

Series: MBMG Bulletin 19

Date: 1960

This is one of the more minimal MBMG Bulletins ever published. Generalized geologic map at scale of about 1:125,000 shows general geologic setting to be till (ground moraine) overlying upper Cretaceous rocks. There are outcrops of Bearpaw Shale within the site section, but map scale is uninformative. Probably shaley till overlying marine shale. Portions of the wetland complex probably are in contact with alluvium, but aquifer characteristics of alluvium are probably not generous unless stratified glacial materials are involved.

No water quality from the site township.

Bibliographic source: Geoindex lat-long search

Author: Colton, R.B., R.W. Lemke and R.M. Lindvall

Title: Glacial map of Montana east of the Rocky Mountains

Series: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-327

Date: 1961

Regional mapping of surficial glacial features at 1:500,000 scale shows Black Coulee apparently within a band of marginal morainal deposits ringing the Turner-Hogeland plateau. This deposit is presumably(?) related to the glacial advance which did not override the bench, rather than to the advance responsible for the glacial deposits ("ground moraine") shown on the bench surface.

Blackfoot Meadows

Bibliographic source: Geoindex lat-long search

Author: Ruppel, E.T.

Title: Geology of the Basin quadrangle, Jefferson, Lewis and Clark and Powell Counties, Montana

Series: USGS Bulletin 1151

Date: 1963

This map emphasizes the igneous units of the quadrangle (mapped at 1:48000) and provides no real information on unconsolidated deposits. All the unconsolidated deposits along the upper Little Blackfoot are mapped as glacial undivided - seems questionable. The exposed igneous units in the immediate vicinity of Blackfoot Meadows are mapped as rhyolite flows, flow breccias and tuffs of Tertiary age, with some underlying Cretaceous Elkhorn Volcanics (welded tuff facies) also exposed. The basin above Blackfoot Meadows is underlain dominantly by felsic volcanics, many tuffaceous.

Blackfoot WPA

Bibliographic source: U.S. Geological Survey bibliographic search of the Blackfoot valley area.

Author: Weber, M.W. and I.J. Witkind

Title: Reconnaissance geologic map of the western half of the Marcum Mountain quadrangle, Powell County, Montana

Series: U.S. Geological Survey Open-file report 79-445

Date: 1979

Detailed surficial geologic mapping at 1:24,000 scale shows the Blackfoot WPA site underlain by "Older Pinedale" outwash(?) of late Pleistocene age. Outwash materials are described as moderately well sorted in character. Outwash surface appears to merge into the modern Blackfoot River floodplain just south of the WPA.

Upland outcrops within the contributing drainage basin are mapped as undifferentiated Proterozoic (Belt) formations.

Bibliographic source: Geindex lat-long search

Author: Wallace, C.A.

Title: Generalized geologic map of the Butte 1 degree X 2 degree sheet, Montana

Series: U.S. Geological Survey Miscellaneous Field Studies Map MF-1925.

Date: 1987

Regional bedrock geologic compilation at 1:250,000 scale shows the contributing surface-water basin underlain by undifferentiated

Ravalli Group (Spokane, Empire and Greyson Formations) of Proterozoic (Belt) age. Nearby areas are shown as underlain by granodiorite of Late Cretaceous age and by intermediate to mafic volcanic rocks of Eocene and Oligocene (early to mid Tertiary) age. [Mineralization can be inferred from the presence of the intrusive body and from the local name "Mineral Hill".]

Brush Lake and White Lake

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index

Author: Reiten, J.C.

Title: Water quality of selected lakes in Sheridan County, Montana

Series: MBMG Open-file report 244

Date: 1991(?)

This publication describes the results of a 1990 survey of the water quality of more than 50 lakes in Sheridan County, with comparisons to previous (1984) field surveys of lake specific conductance. The lakes sampled include Brush Lake, Mallard Pond, White Lake, North Goose, North Widgeon Slough and Lone Tree. Limited geochemical interpretations include the development of an empirical "contamination index" based on molar ratios of chloride ion to other anions.

A poor-quality map at approximately 1:125,000 scale shows classification of the sampled lakes according to a 5 - class system based on specific conductance.

Bibliographic source: Montana Bureau of Mines and Geology
Publication Index

Author: Donovan, J.J.

Title: Ground-water geology and high-yield aquifers of northeastern Montana.

Series: MBMG Open-file report 209

Date: 1988

This document is the most current and comprehensive investigation of the northeastern Montana gravel aquifers which interact with many lakes and wetlands in the area, including the wetland sampling program sites of Brush Lake, White Lake, Mallard Pond, Gaffney Lake

and Medicine Lake. This publication includes analyses of water chemistry and aquifer characteristics and their general relationships with surface water. Regional water budget analyses are described with a MODFLOW two dimensional model of the Clear Lake and tributary aquifers. Historical records of ground-water elevations are included.

Map coverage at 1:100,000 scale shows the interpreted extent of high-yield gravel aquifers with respect to lakes of the region.

Bibliographic source: None - personal collection

Author: Donovan, J.J.

Title: Geochemical and hydrologic dynamics in evaporative groundwater-dominated lakes of glaciated Montana and North Dakota

Series: Doctoral dissertation, Pennsylvania State University

Date: 1992

The geochemistry of Brush and White Lakes is described in detail in this dissertation. Field data include detailed geochemistry of ground water, lakes, and sediments. Mass balance relationships (water and solutes) for Brush Lake are derived from geochemical and hydrogeologic arguments. Post-Pleistocene historical development of the modern Brush Lake/White Lake geochemistry is modeled.

The analysis includes interpretations of regional climate and groundwater mechanisms with relevance to other Sheridan County sample program sites.

Bibliographic source: Geotitles lat-long search

Author: Witkind, I.J.

Title: Quaternary Geology of the Smoke Creek - Medicine Lake - Grenora Area, Montana and North Dakota.

Series: USGS Bulletin 1073

Date: 1959

Geologic mapping at 1:62,500 scale shows both lakes underlain by Late Wisconsin ("Mankato") outwash. The lakes are situated near the confluence of the Stady and Grenora channels, with the till ridge between the two extending northeastward from the lakes. White Lake is nearer to the (southern) boundary of the

Stady/Grenora channel, with Brush Lake near the midpoint. A major esker trends eastward from a point northeast of White Lake. There is some limited geophysical and other subsurface information which is probably all superseded by later MBMG and USGS hydrogeologic work.

Burns Creek

Bibliographic source: Geoindex lat-long search

Author: Colton, R.B., R.W. Lemke and R.M. Lindvall

Title: Glacial map of Montana east of the Rocky Mountains

Series: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-327

Date: 1961

Regional mapping of glacial surface features at 1:500,000 scale shows the Burns Creek site at the margin of the maximum extent of glaciation across the Burns Creek drainage. This mapping shows outwash deposition above the North Fork-Middle Fork confluence and below the sample site, with a gap between. The North Fork Burns Creek drainage way is shown as continuous with the Fox Creek-Redwater Creek drainage to the north.

According to this interpretation, glacially transported calcareous materials may underlie both the Burns Creek system and Fox Lake, both of which are underlain by noncalcareous (Fort Union Formation) bedrock.

Bibliographic source: Geoindex lat-long search

Author: Prichard, G. E. and E.R. Landis

Title: Coal resources and Cenozoic geology of the Girard coal field, Richland County, Montana

Series: USGS Bulletin 1310

Date: 1975

Geologic mapping at 1:62,500 scale includes the North Fork of Burns Creek at the southwesternmost corner of the map area, some distance upstream of the sampling site. The North Fork above the alluvium is shown as the Tongue River member of the Fort Union Formation, with areas of mappable clinker. Upland areas along divides have extensive areas mapped as the Flaxville Formation.

There is a fairly extensive discussion of geomorphology and Late Tertiary - Quaternary geology, but no discussion of hydrologic characteristics. The position of the mapped extent of Pleistocene glaciation with respect to the sample site is not shown.

Bibliographic source: Geoindex lat-long search

Author: Torrey, A.E. and F.A. Kohut

Title: Geology and ground-water resources of the lower Yellowstone River Valley, between Glendive and Sidney, Montana

Series: USGS Water-Supply Paper 1355

Date: 1956

Geologic mapping at 1:126,720 scale is restricted to the Yellowstone Valley and the lowermost sections of the tributaries. Lower Burns Creek is mapped as alluvium incised into till, with occasional outcrops of undivided Fort Union Formation shown along adjacent reaches of the Yellowstone.

Page 16 has a brief but interesting discussion of the behavior of tributaries, including Burns Creek, as drains for the irrigated terraces of the Yellowstone. There is no discussion of the hydraulic characteristics or water quality of the tributary alluvium.

Colter Campground

Bibliographic source: Geoindex lat-long search

Author: Elliot, J.E.

Title: Geologic map of the southwest part of the Cooke City Quadrangle, Montana and Wyoming.

Series: U.S. Geological Survey Miscellaneous Investigations Series Map I-1084.

Date: 1979

Detailed bedrock geologic mapping at 1:24000 scale shows the Colter Campground wetland underlain by "granitic rocks" (mainly granite gneiss) of Precambrian W age (approximately 2,750 m.y.). Surficial sediments are shown as a narrow (and presumably thin) band of

undifferentiated glacial deposits extending barely beyond the wetland. No description of the character of glacial deposits in the area is included.

Up-slope areas within the apparent surface catchment may include mafic metamorphic rocks (metadolerite) of Precambrian W age. Nearby outcrops of Cambrian-aged rocks (including the Meagher Limestone and other calcareous lithologies) appear to be outside of the surface catchment of the wetland site, but may have contributed material to the glacial sediments exposed at the site surface.

Comertown Preserve

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index.

Author: Bergantino, R.N.

Title: Quaternary geology of the Wolf Point 1 degree X 2 degree quadrangle.

Series: MBMG Open-file report 172

Date: 1986

Regional map compilation (blue-line) at approximately 1:250,000 scale shows both Comertown and North Widgeon sites underlain by Late Wisconsin(?) till. [Regionally, this till deposit is typically described as having a significant fraction of calcareous material.] Mapping shows some isolated areas underlain by ice-contact stratified drift within the Lone Tree Lake 7.5' quadrangle.

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index.

Author: Bergantino, R.N.

Title: Prequaternary geology of the Wolf Point 1 degree X 2 degree quadrangle.

Series: MBMG Open-file report 171

Date: 1986

Regional map compilation (blue-line) at approximately 1:250,000 scale shows surficial glacial materials of the Comertown Preserve and North Widgeon wetland sites to be underlain by undifferentiated Fort Union Formation of early Tertiary (Paleocene) age. This map

shows regional outcrop distribution only, and does not include any structural information or local lithologic descriptions.

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index.

Author: Donovan, J.J.

Title: Ground-water geology and high-yield aquifers of
northeastern Montana

Series: MBMB Open-file report 209

Date: 1988

Aquifer mapping at 1:100,000 scale shows Comertown Preserve to be well outside the distribution of high-yield gravel aquifers.

Condon Creek Proposed RNA, #1 and #2.

Bibliographic Source: Geoindex lat-long search.

Author: Mudge, M.R and R.L. Earhart

Title: Geologic Map of the Bob Marshall and Great Bear
Wildernesses and Adjacent Study Areas, Northwestern
Montana.

Series: U.S. Geological Survey Miscellaneous Investigations Series
Map I-2181

Date: 1991

Map coverage at 1:125,000 scale covers the Swan Range above the site but not the lower slopes or lowland areas. Mapped formations upgradient of the wetland site include the Spokane formation, the Empire Formation and the Helena Formation (all Proterozoic Y in age) with the Late Proterozoic diorite occurring near the Swan divide.

The Spokane Formation is described as dominantly thin-bedded siltite with subordinate argillite and quartzite. The overlying Empire Formation (transitional between Spokane and Helena) is described as dominantly calcareous to dolomitic argillite, with subordinate dolomite and quartzite interbeds. The Helena Formation is described as mainly limestone, dolomite and calcitic dolomite,

with subordinate dolomitic siltite and argillite. Stromatolitic and oolitic beds and molar tooth structures described in upper portions of the unit. Dips are to the east at 25 to 40 degrees.

The upper portion of the range-front fan complex is mapped as a band of colluvium below the Proterozoic outcrops. No other information regarding surficial deposits of the sample site is provided.

Creedman Coulee

Bibliographic source: Geoindex lat-long search

Author: Colton, R.B., R.W. Lemke and R.M. Lindvall

Title: Glacial map of Montana east of the Rocky Mountains

Series: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-327

Date: 1961

Regional mapping of surficial glacial features shown the Creedman Coulee area underlain by till ("ground moraine").

Bibliographic source: None - default reference.

Author: Ross, C.P., D.A. Andrews and I.J. Witkind

Title: Geologic map of Montana

Series: U.S. Geological Survey, no series

Date: 1955

Statewide compilation at 1:500,000 scale shows the Creedman Coulee basin in Montana underlain mainly by the Bearpaw Shale of Late Cretaceous age, with some Late Cretaceous Judith River Formation underlying the western tributaries. The geology of the Canadian portion of the basin is not shown.

This map shows generalized prequaternary geology only, and provides no information regarding surficial deposits. Presumably the Creedman Coulee basin surficial materials are glacial deposits of unknown thickness and character.

Neither the Geoindex lat-long search nor manual searching of the Montana Bureau of Mines and Geology produced any more useful geologic map coverage for this area.

Dudley Slough

Bibliographic source: Geoindex lat-long search

Author: Coffin, D.L., A. Brietkrietz and R.G.McMurtrey

Title: Surficial geology and water resources of the Tobacco and upper Stillwater river valleys, northwestern Montana

Series: Montana Bureau of Mines and Geology Bulletin 81

Date: 1971

Regional map coverage at 1:84,500 scale shows the Dudley Slough site to be underlain by undifferentiated Belt metasediments, and outside the lowland areas of major glacial deposition.

Bibliographic source: Geoindex lat-long search

Author: Johns, W.M.

Title: Geology and mineral deposits of Lincoln and Flathead counties, Montana

Series: Montana Bureau of Mines and Geology Bulletin 79

Date: 1970

Regional mapping at 1:125,000 shows the general area of Dudley Slough crossed by the contact between the Siyeh Formation and the "Lower Piegan Unit". The Siyeh is described as dolomite and limestone, commonly pyritic. The Lower Piegan is dominantly argillite, often calcareous and sometimes with limestone lenses.

Bibliographic source: None - DHES collection

Author: Rabe, F.W., R.L. Bursik and E.B. Cantor

Title: Classification and monitoring of wetlands in established

and proposed natural areas.

Series: Project report on USDA Forest Service Intermountain Research Station Proposal #89009.

Date: 198?

This document provides a partial chemical analysis for Dudley Sluogh from July 1988, a reported maximum depth of 6 meters, and biological inventory data.

Evans Lake

Bibliographic source: None - personal collection

Author: Dea, Peter

Title: Glacial geology of the Ovando Valley, Powell County, Montana

Series: University of Montana M.S. thesis in geology

Date: 1982

Detailed surficial geologic mapping at approximately 1:40,000 scale shows Evans Lake underlain by till of the late Pleistocene North Fork advance. Evans Lake is approximately 1 mile from the western limit of North Fork till as mapped by Dea. Dea's study focused on the deposits of the Clearwater and Monture advances, and does not attempt to interpret stratigraphic relationships between the North Fork till and the outwash deposits contacting the till. [The Copenhagen Park well log, if it exists, might clarify this relationship.] It is possible that marginal Monture Creek and/or North Fork outwash underlies Evans Lake at relatively shallow depths.

The Dry Gulch channel is not mapped separately from the North Fork till.

Bibliographic source: Geoindex lat-long search

Author: Mudge, M.R., R.L. Earhart, J.W. Whipple and J.E. Harrison

Title: Geologic and structure map of the Choteau 1 degree X 2 degree quadrangle, Western Montana.

Series: U.S. Geological Survey Miscellaneous Investigations Series

Map I-1300

Date: 1982

Regional compilation of bedrock geologic mapping at 1:250,000 scale shows the North Fork Blackfoot source area for the North Fork till to be underlain by Proterozoic (Belt) formations from the Spokane Formation through the Bonner Formation, including large areas of Helena Formation (dominantly carbonate lithologies) in the lower and middle basin. The upper basin includes areas of undifferentiated Cambrian and Devonian rocks.

Fox Lake

Bibliographic source: Geoindex lat-long search

Author: Colton, R.B., R.W. Lemke and R.M. Lindvall

Title: Glacial map of Montana east of the Rocky Mountains

Series: U.S. Geological Survey Miscellaneous Geologic
Investigations Map I-327

Date: 1961

Regional mapping of glacial surface features at 1:500,000 scale shows Fox Lake near the triple junction between a Redwater Creek-Fox Creek drainage channel and the North Fork Burns Creek channel. Two additional drainage ways are shown extending northwestward to near the drainage divide between the Missouri and Yellowstone drainages. The position of the maximum glacial advance is shown approximately along the drainage divide to the north, then turning due south and crossing Fox Creek just east of Fox Lake and lower Burns Creek. [The North Fork Burns Creek drainage way may have carried meltwaters during times when Fox Creek was impounded but Burns Creek was not.]

The map suggests that this drainage may have been an important one at times of near-maximum advance. Fox Creek and Fox Lake may be overdeepened and underlain in places by gravel sequences similar to Burns Creek.

Bibliographic source: Geoindex lat-long search

Author: Parker, F.S.

Title: The Richey - Lambert Coal Field, Richland and Dawson

Counties, Montana

Series: USGS Bulletin 847-C

Date: 1936

Geologic mapping at 1:62,500 scale shows the Fox Lake area underlain by Quaternary alluvium, undifferentiated between Holocene and Pleistocene. The mapped alluvium is continuous across modern divides to Redwater Creek to the west and the North Fork of Burns Creek to the south. The drainage development and sediment are likely of glacial origin, at least in part. The alluvium is described as being as much as 30 feet thick in Redwater Creek and other larger drainages. There is no discussion of hydraulic characteristics of map units.

Fox Lake was described at the time as perennial but seasonally highly variable in size, and surrounded by salinated flats during low-water periods.

The Redwater Creek - Fox Creek - North Fork Burns Creek channel is interpreted as a mid-Pleistocene (Illinoian or Iowan) diversion channel of the Pleistocene Missouri River. [If this is correct, there may be substantial gravel deposits underlying the channel.] Lacustrine sediments related to ice-marginal impoundments are described in Redwater Creek (and may underlie Fox Lake also). The southern limit of glaciation is shown several miles to the north, on the Missouri side of the Yellowstone/Missouri divide.

Bedrock in the entire Fox Creek drainage is shown as the Tullock Member of the Fort Union Formation.

Freezeout Lake.

Bibliographic source: Geotitles lat-long search

Author: Colton, R.B., R.W. Lemke and R.M. Lindvall

Title: Glacial map of Montana east of the Rocky Mountains

Series: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-327

Date: 1961

Regional mapping of glacial surface features at 1:500,000 scale shows Freezeout Lake (shown as Greenfield Lake on this map) near the western limit of Glacial Lake Great Falls and outside of the maximum extent of glacial advance.

Bibliographic source : Geoindex lat-long search

Author: Mudge, M.R., R.L. Earhart, J.W. Whipple and J.E. Harrison

Title: Geologic and structure map of the Choteau 1 X 2 degree quadrangle, western Montana.

Series: MBMG Montana Atlas MA 3-A.

Date: 1982

The scale (1:250,000) limits the usefulness of this map to regional overview. Map shows the Freezeout (?) basin underlain throughout by glaciolacustrine deposits (of glacial Lake Great Falls?). The glaciolacustrine sediments on the sheet are described as up to 30 meters in thickness. Uplands to the north are shown as underlain by glacial materials overlying undivided Marias River Shale (Upper Cretaceous). Uplands to the west and south are shown as Marias River, Virgelle/Telegraph Creek and Two Medicine, all undivided, all upper Cretaceous and with the exception of the Virgelle all essentially non-aquifers.

Bibliographic source: Inquiry to U.S. Geological Survey

Author: Lambing, J.H., D.A. Nimick, J.R. Knapton and D.U. Palwski

Title: Physical, chemical and biological data for detailed study of the Sun River Irrigation Project, Freezeout Lake Wildlife Management Area, and Benton Lake National Wildlife Refuge, west-central Montana, 1990-92, with selected data for 1987-89.

Series: U.S. Geological Survey Open-file report 94-120

Date: 1994

This document contains descriptions of the data collection programs initiated in and around Freezeout and Benton Lakes in 1990, and tabulations of soil, surface water and ground water, lake sediment and bioassay data. Interpretation of these data is pending.

The data assembled include numerous drill-hole descriptions, ground-water level measurements and water quality analyses from the Greenfields Irrigation District south and east of Freezeout, comprehensive water quality analyses from all Freezeout Lake ponds, and bottom sediment analyses from two sites in the main lake and from Pond #1, and numerous soil analyses from irrigated and unirrigated areas south and east of the lake.

Bibliographic source: U.S. Geological Survey office inquiry

Author: Knapton, J.R., W.E. Jones and J.W. Sutphin

Title: Reconnaissance investigation of water quality, bottom sediment and biota associated with irrigation drainage in the Sun River area, west-central Montana

Series: U.S. Geological Survey Water-Resource Investigations report 87-4244

Date: 1987

This study included limited ground-water sampling in the Greenfields Bench gravels, and water quality and bottom sediment analyses from Pond #1 and from the south end of main Freezout Lake, and from Priest Butte Lake.

Statistical summaries of the data and a comprehensive bibliography are included.

Furnell WPA

Bibliographic source: Geoindex lat-long search

Author: Ross, C.P

Title: Fluorspar prospects of Montana

Series: USGS Bulletin 955-E

Date: 1950

Map coverage includes the Furnell area but emphasizes igneous map units only, does not provide information on the geology of the area East and Middle Buttes.

Bibliographic source: Geoindex lat-long search

Author: Colton, R.B., R.W. Lemke and R.M. Lindvall

Title: Glacial map of Montana east of the Rocky Mountains

Series: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-327

Date: 1961

Regional mapping of surficial glacial features at 1:500,000 scale

shows the till in the Furnell area to be part of a significant end moraine complex related to a glacial advance position extending through but not beyond the gaps between the buttes of the Sweetgrass Hills. Beyond the mapped extent of end moraine, this map shows till ("ground moraine"), presumably related to older glacial advances.

Bibliographic source: Montana State Library optical disk catalog

Author: Tuck, L.K

Title: Reconnaissance of geology and water resources along the north flank of the Sweet Grass Hills, north-central Montana

Series: U.S. Geological Survey Water-Resource Investigations Report 93-4026

Date: 1993

Reconnaissance geologic mapping at 1:100,000 scale shows the site overlying the shaley upper part of the Eagle Sandstone of Late Cretaceous age. The western part of the kettle field is shown underlain by Late Cretaceous Claggett Shale. Till underlying the sample wetland and adjacent kettles is not shown. The text states that glacial deposits typically do not exist much above 5000 feet, and probably do not exceed 50 feet in thickness in foothill areas (references include several on glacial geology). The Claggett Shale is described as "nearly impermeable" and as having bentonite beds, especially in it's lower portion.

Generalized potentiometric surfaces are mapped for the aquifers identified in the area (including the "interstratified sand and gravel aquifer" of glacial origins), but do not extend as far south as the sample site, where there do not appear to be any data.

Three chemical analyses from groundwater in glacial deposits between the sample wetland and Whitlash show calcium-bicarbonate ($\pm$ sulfate) water types with total dissolved solids between 300 and 700 mg/l.

This publication includes what appears to be a thorough review of geologic literature pertinent to the Sweet Grass Hills, including some with relevance to the Oilmont Wetland site.

Bibliographic source: U.S. Geological Survey WRI 93-4026 (see Furnell WPA entry.)

Author: Lemke, R.W., W.M. Laird, M.J. Tipton and R.M. Lindvall

Title: Quaternary geology of the northern Great Plains in: The Quaternary of the United States; a review volume for the VII Congress of the International Association for Quaternary research.

Series: Princeton University Press

Date: 1965

This is a regional review of glacial and glaciolacustrine limits, regional depositional features and correlations. It does not describe glacial sediments in any detail, but does show the till in the gap of the Sweetgrass Hills as part of a "prominent end moraine" wrapped around the northern side of the range.

Gaffney Lake

Bibliographic source: Montana Bureau of Mines and Geology Publications Index

Author: Donovan, J.J.

Title: Ground-water geology and high-yield aquifers of northeastern Montana.

Series: MBMG Open-file report 209.

Date: 1988

See Brush Lake entry for description of the publication. Regional isopach mapping of Clear Lake and pre-glacial terrace gravel aquifers shows Gaffney Lake overlying a relatively thick composite section of permeable aquifer material. Field data include 4 specific conductance measurements from different parts of Gaffney collected in 1984. Regional ground-water flow modeling indicates substantial ground-water discharge from the Clear Lake aquifer to Medicine Lake, also to Gaffney??

Bibliographic source: Montana Bureau of Mines and Geology Publications Index

Author: Bergantino, R.N.

Title: Prequaternary geology of the Wolf Point 1 degree X 2 degree quadrangle.

Series: MBMG Open-file report 171

Date: 1986

Regional map compilation at 1:250,000 scale shows surficial deposits in the Gaffney Lake area underlain by undifferentiated Fort Union Formation of early Tertiary (Paleocene) age.

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index.

Author: Bergantino, R.N.

Title: Quaternary geology of the Wolf Point 1 degree X 2 degree quadrangle.

Series: MBMG Open-file report 172

Date: 1986

Regional compilation at 1:250,000 scale shows Gaffney Lake straddling the contact between Late Wisconsin outwash deposits and an extensive area of ice-contact stratified drift (probably a kame terrace) occupying the southern margin of the Medicine Lake swale.

Bibliographic source: Geoindex lat-long search

Author: Witkind, I.J.

Title: Quaternary geology of the Smoke Creek-Medicine Lake-Grenora area, Montana and North Dakota.

Series: U.S. Geological Survey Bulletin 1073

Date: 1959

Hailstone and Halfbreed National Wildlife Refuges.

Bibliographic source: Shelf search of MBMG collection.

Author: Feltis, R.D.

Title: Hydrogeologic map of the Billings 1 X 2 quadrangle and vicinity, Montana

Series: MBMG Hydrogeologic Map 9

Date: 1988

The Billings 1 X 2 sheet (1:250,000) just barely includes Halfbreed and Hailstone (??) at it's northern margin. The maps shows outcrop area and Stiff diagrams of water quality for different aquifers, along with some subsurface structural information.

Map 9F, showing data for Upper Cretaceous through Quaternary aquifers, shows nothing for the Hailstone/Halfbreed area.

Map 9E, showing data from Eagle sandstone through the Bearpaw shale, shows the Eagle underlying both basins at depths of a few hundred feet. The few nearby chemical analyses shown from the Eagle and Judith River aquifers are sodic with subequal sulfate and bicarbonate concentrations and TDS up to 5300.

Map 9-D, showing the Dakota sandstone through Telegraph Creek Formations, shows top of Dakota sandstone at a depth of a couple of thousand feet. Chemical analyses shown indicate highly variable water quality, with Frontier Fmn analyses ranging up to 26400 mg/l but also down to less than 2000 mg/l. Dakota analyses similarly variable.

9-A through C provide data for older, deeper aquifers.

Hewitt Lake.

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index

Author: Perry, E.S.

Title: Geology and artesian water resources along Missouri and Milk Rivers in northeastern Montana.

Series: MBMG Memoir 11

Date: 1934

The emphasis of this outdated but interesting report is on the hydrologic and hydrogeologic impacts of the Fort Peck Reservoir and dam, under construction at the time. The document includes a generalized geologic map at a scale of about 1:125,000 showing the Hewitt Lake area underlain by undifferentiated formations "older than the Judith River Formation". [Apparently Claggett Shale.]

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index

Author: Bergantino, R.N.

Title: Altitude of the top of the Claggett Shale, Glasgow 1 degree
X 2 degree quadrangle.

Series: MBMG Open-file report 182

Date: 1987

Regional map at 1:250,000 scale shows Hewitt Lake and all of it's contributing drainage underlain by the Claggett Shale of Late Cretaceous age. Hewitt Lake overlies the apex of a structural dome (the Bowdoin Dome??), which presumably forms a structural trap for the hydrocarbons extracted from the underlying natural gas field.

This publication is a blue-line map with no accompanying text or hydrologic information. Surficial deposits are not shown.

Homestead Lake.

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index.

Author: Bergantino, R.N.

Title: Quaternary geology of the Wolf Point 1 degree X 2 degree
quadrangle.

Series: MBMG Open-file report 172

Date: 1986

Regional compilation at 1:250,000 scale shows Homestead Lake underlain by undifferentiated "alluvium" of Big Muddy Creek. [Note that other sources indicate outwash deposits probably underlie the Big Muddy valley in this area - see Donovan, 1988.]

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index.

Author: Bergantino, R.N.

Title: Prequaternary geology of the Wolf Point 1 degree X 2

degree quadrangle.

Series: MBMG Open-file report 171

Date: 1986

Regional compilation at 1:250,000 scale shows Homestead Lake underlain by undifferentiated Fort Union Formation of Early Tertiary (Paleocene) age.

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index

Author: Donovan, J.J.

Title: Ground-water geology and high-yield aquifers of
northeastern Montana.

Series: MBMG Open-file report 209.

Date: 1988

See Brush Lake entry for description of the publication. Mapping of aquifer distribution indicates that Homestead Lake is underlain by permeable aquifers of outwash and/or preglacial terrace gravel origins. Potentiometric data presented which indicate relatively efficient connections between Homestead Lake and terrace gravel aquifers nearby.

Hoskins Lake.

Bibliographic source: Geindex lat-long search.

Author: Van Loenen, R.E.

Title: Geologic map of the Mount Henry roadless area, Lincoln County, Montana.

Series: Miscellaneous Field Studies Map MF-1534-A.

Date: 1984

Mapping at 1:50,000 scale shows the immediate area of Hoskins Lake

underlain by "alluvium" (more likely dominated by paludal and/or lacustrine deposits). Glacial deposits are shown along the margins of the Yaak valley and just to the south of the Hoskins Lake basin. Quite possible a veneer of glacial material beneath Hoskins Lake "alluvium". No discussion of the character of unconsolidated sediments.

Middle Belt outcrops are mapped on both sides of Hoskins Lake. The Middle Member of the Wallace Formation is shown on the ridge to the west and the lower slopes of the ridge to the east. The lower member of the Wallace is shown to the north, and the St. Regis Formation outcrops on the higher slopes of the ridge to the east. Both Wallace members contain limestone and dolomite interbeds, apparently more common in the lower member, within dominantly argillaceous sequences. The calcareous interbeds and lenses are described as frequently pyritic.

The lake basin overlies the trace of a north-south high angle fault, one of several such structures traversing the map area.

Bibliographic source: None - DHES collection

Author: Rabe, F.W. and S.Chadde

Title: Aquatic features of Research Natural Areas on the Kottenai and Flathead National Forests, Montana.

Series: None - USDA Forest Service(?) unnumbered report

Date: 1995

This document provides partial chemical analyses of Hoskins Lake and "Hoskins Pond" to the north, along with limited depth information from both. Field measurements showed modest vertical pH and salinity gradients in Hoskins Pond, with slightly higher dissolved solids and slightly lower pH near the pond bottom. The maximum measured depth near the center of Hoskins Pond was 8.5 meters, and the maximum depth along a single transect across the north end of Hoskins Lake was 7.5 meters. Drainage into and out of Hoskins Lake is described as intermittent (without supporting data).

The biological inventory of Hoskins Lake describes an abundance of the freshwater sponge *Spongilla lacustris*.

Indian Meadows.

Bibliographic source: Geoindex lat-long search.

Author: Mudge, M.R., R.L. Earhart, K.C. Watts, E.T. Tuckek and W.L.

Rice.

Title: Mineral resources of the Scapegoat Wilderness, Powell and Lewis and Clark Counties, Montana.

Series: USGS Bulletin 1385-B

Date: 1974

The Indian Meadows RNA is just off the southern edge of the mapped area. Contiguous areas are shown as undifferentiated glacial materials or as "gravels" without specified origins. Map scale of 1:96,000.

Upstream areas of this and adjacent drainages are mapped as entirely Precambrian Belt formations, with extensive areas of Helena Formation outcrop.

Bibliographic source: Geoindex latlong search

Author: Whipple, J.W., M.R. Mudge and R.L. Earhart

Title: Geologic map of the Rogers Pass area, Lewis and Clark County, Montana.

Series: U.S. Geological Survey Miscellaneous Investigations Series Map I-1642

Date: 1987

Excellent bedrock geologic map at 1:48000 scale shows outcrop on the north side of Indian Meadows (Lone Mountain) as Oligocene(?) /Miocene(?) sediments, described as dominantly clastic with minor marlstone and limestone, locally carbonaceous and locally tuffaceous. [Note that other references describe this unit as pyritic in this area.] Outcrops to the south of the wetland area are shown as tuff of the Oligocene(?) and Eocene Crater Mountain Volcanics. Structurally, the area is shown near the eastern edge of the Scapegoat thrust plate, with the (buried) Scapegoat thrust trace inferred to pass 1-2 miles to the east.

The Indian Meadows area proper is shown underlain by undifferentiated glacial deposits. Note that the modern contributing basin includes no mapped Belt or other Proterozoic units. However, glacial or glaciofluvial transport from the North Fork of Copper Creek undoubtedly contributed sediment derived from large areas underlain by the Proterozoic Y Helena Formation (dominantly calcareous and dolomitic) and the overlying Snowslip Formation (dominantly siltite and argillite), and probably from areas underlain by Cambrian and Devonian sediments, dominantly

calcareous and dolomitic in composition.

Bibliographic source: None - DHES collection

Author: Rabe, F.W., R.L. Bursik and E.B. Cantor

Title: Classification and monitoring of wetlands in established and proposed natural areas.

Series: Project report on USDA Forest Service Intermountain Research Station Proposal #89009.

Date: 198?

This document provides a partial chemical analysis from some site in Indian Meadows in June of 1987, along with biological inventory data. The location and site description are insufficient to confirm that the site or even the water body was the same as WET28.

Jarina

Bibliographic source: Geoindex lat-long search

Author: Colton, R.B., R.W. Lemke and R.M. Lindvall

Title: Glacial map of Montana east of the Rocky Mountains

Series: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-327

Date: 1961

Regional mapping of surficial glacial features at 1:500,000 scale shows the Jarina area near the eastward margin of the maximum extent of alpine glaciation, near the mapped narrow point of the unglaciated corridor between alpine and continental glacial margins.

Bibliographic source: Geoindex lat-long search

Author: Mudge, M.R. and R.L. Earhart

Title: Geologic map of the Bob Marshall and Great Bear Wildernesses and adjacent study areas, northwestern Montana

Series: USGS Miscellaneous Investigation Series Map I-2181

Date: 1991

Regional mapping at 1:125,000 scale appears to end at boundary of Bob Marshall Wilderness and proposed additions, and does not provide map coverage of the area.

Bibliographic source: Geoindex lat-long search

Author: Mudge, M.R. and R. L. Earhart

Title: Bedrock geologic map of the northern Disturbed Belt, Lewis and Clark, Teton, Pondera, Glacier, Flathead, Cascade and Powell Counties, Montana

Series: USGS Miscellaneous Investigations Series Map I-1375

Date: 1983

Regional mapping at 1:125,000 scale provides generalized coverage of sample area. Exposed units in the general area include the Saint Mary Formation, the Two Medicine Formation, undifferentiated Virgelle sandstone/Telegraph Creek Formation, and the Marias River Shale, all Upper Cretaceous in age. Five thrust faults traverse the general area, striking northwestward. The map scale is too small to be sure which of the map units underlie the sample site - possibly all of the above. The Bearpaw Shale is not mapped in the immediate area.

Lithologies described are dominantly fine-grained, with the Virgelle sandstone and interbeds within the Two Medicine Formation representing the most permeable-sounding lithologies, mudstones predominating elsewhere. Shallow to moderate dips to the southwest.

This map includes no information on hydrology or surficial geology.

Bibliographic source: Geoindex lat-long search

Author: Stebinger, E.

Title: Oil and gas geology of the Birch Creek - Sun River area, northwestern Montana

Series: USGS Bulletin 691-E

Date: 1918

Regional mapping at 1:125,000 scale includes the Jarina wetland area at the northern extremity of the map area. Till shown underlying most of the area, with the 'Horsethief Sandstone'

inferred to underlie the till beneath most of the area. [The Horsethief is a coarsening-upward transition from the underlying Bearpaw Shale, according to current use.] The text describes the Horsethief as massive and resistant. The Saint Mary Formation, also late Cretaceous, overlies the Horsethief and may underlie the western portion of the Jarina area. There is no specific information on the characteristics of the till or other surficial deposits shown.

Kingsbury WPA

Bibliographic source: Geoindex lat-long search

Author: Colton, R.B., R.W. Lemke and R.M. Lindvall

Title: Glacial map of Montana east of the Rocky Mountains

Series: U.S. Geological Survey Miscellaneous Geologic
Investigations Map I-327

Date: 1961

Regional mapping of surficial glacial features at 1:500,000 scale shows Kingsbury Lake (identified as Mallard Lake on this map) immediately south of the maximum extent of Pleistocene glaciation. The lake basin is shown to be within apparent ice-marginal drainage way connecting Lepley's Creek to the northwest, Kingsbury Lake and Flat Creek to Arrow Creek to the southeast. Other nearby lakes (Crane, Teal, Shonkin and Gravel) are shown as within the margin of maximum glacial advance. The divide between Kingsbury Lake and Geraldine is shown to have been glaciated.

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index

Author: Duaime, T.E., H.R. Moore, J.M. Holzer and G.A. Hockett

Title: Saline seep assessment of Geraldine, Montana and
surrounding areas.

Series: MBMG Open-file report 169

Date: 1986

The study area for this research was limited to a radius of about 2.5 miles around Geraldine and thus does not include data from the Kingsbury Lake basin. It does include water quality data from shallow groundwater sources (wells and springs) and documents the

historical changes in ground-water quality in seep-impacted areas. The text includes qualitative but potentially useful interpretations of geochemical processes leading to seep development in this area.

Bibliographic source: Geotitles lat-long search

Author: Reeves, F.

Title: Thrust faulting and oil possibilities in the plains adjacent to the Highwood Mountains, Montana

Series: USGS Bulletin 806

Date: 1928

Regional geologic mapping at 1:250,000 scale covers the Kingsbury (aka Mallard) Lake area. Reeves shows Kingsbury Lake to be underlain by Colorado Shale and to be situated immediately south of the southern limit of glacial drift deposition. Dikes related to the Highwood Mountains intrusive event are mapped immediately to the southwest, west and northwest. Surficial deposits of the Kingsbury basin are not shown. Includes a discussion of the lithologic characteristics of the Colorado shale (sandstone and sandy shale beds are common lower in the section.) No discussion of hydrology included.

Kleinschmidt Lake.

Bibliographic source: U.S. Geological survey compilation of Blackfoot Valley references

Author: Weber, W.M. and I.J. Witkind

Title: Reconnaissance geologic map of the Browns Lake quadrangle, Powell County, Montana

Series: U.S. Geological Survey Open-file report 79-439

Date: 1979

Detailed surficial geologic mapping at 1:24,000 scale shows

Kleinschmidt Lake underlain by "Younger Pinedale" till of the North Fork provenance. The contact with the outwash gravels forming Kleinschmidt Flat is about 1 mile northeast of Kleinschmidt Lake. No information regarding stratigraphic relations is provided, but from surface relationships it appears possible that advance outwash deposits might underlie till in the vicinity of Kleinschmidt Lake.

Bibliographic source: Geoindex lat-long search

Author: Mudge, M.R., R.L. Earhart, J.W. Whipple and J.E. Harrison

Title: Geologic and structure map of the Choteau 1 degree X 2 degree quadrangle, Western Montana.

Series: U.S. Geological Survey Miscellaneous Investigations Series Map I-1300

Date: 1982

Regional compilation of bedrock geologic mapping at 1:250,000 scale shows the North Fork Blackfoot source area for the North Fork till to be underlain by Proterozoic (Belt) formations from the Spokane Formation through the Bonner Formation, including large areas of Helena Formation (dominantly carbonate lithologies) in the lower and middle basin. The upper basin includes areas of undifferentiated Cambrian and Devonian rocks.

LaFoe Lake

Bibliographic source: Geoindex lat-long search

Author: Johns, W.M.

Title: Geology and mineral deposits of Lincoln and Flathead counties, Montana

Series: Montana Bureau of Mines and Geology Bulletin 79

Date: 1970

Regional mapping at scale of approximately 1:125,000 shows the entire contributing drainage underlain by the calcareous and dolomitic Wallace Formation of Proterozoic Y (Belt) age. The Quartz Creek Fault, a normal fault downdropped to the west, is shown immediately underlying the Lafoe Lake wetland, raising the

possibility that the wetland may be structurally controlled in some sense.

This map shows only larger areas of surficial deposits, and provides no information on Quaternary sediments in the Lafoe Lake area.

Bibliographic source: None - DHES collection

Author: Rabe, F.W., R.L. Bursik and E.B. Cantor

Title: Classification and monitoring of wetlands in established and proposed natural areas.

Series: Project report on USDA Forest Service Intermountain Research Station Proposal #89009.

Date: 198?

This report provides a partial chemical analysis from June of 1987 and results of biological inventory of LaFoe Lake.

Lahrity Lake

Bibliographic source: None - Personal collection

Author: Dea, Peter.

Title: Glacial geology of the Ovando Valley, Powell County, Montana

Series: University of Montana Master's Thesis in Geology

Date: 1982

Detailed surficial geologic mapping at approximately 1:40,000 scale shows Lahrity Lake underlain by late Pleistocene till of the Monture Creek advance. Till and outwash of the Clearwater advance are mapped on the flanks of Monture Hill, and appear to be shown underlying the Lahrity Lake Southwest site. This is a stratigraphically complex area where glacial deposition was probably strongly influenced by the presence of Monture Hill.

Bibliographic source: Personal collection

Author: Lesica, Peter

Title:

Series: None

Date:

Bibliographic source: Geoindex lat-long search

Author: Mudge, M.R., R.L.Earhart, J.W.Whipple, and J.E. Harrison

Title: Geologic and structure map of the Choteau 1 degree X 2 degree quadrangle, western Montana

Series: U.S. Geological Survey Miscellaneous Investigations Series Map I-1300

Date: 1982

Regional compilation of bedrock geology at 1:250,000 scale shows Monture Hill outcrops in the immediate vicinity of Lahurity Lake to be the Snowslip Formation of Proterozoic Y (Belt) age. The snowslip Formation is described as interbedded argillite and siltite with minor fine-grained quartzite, pebble conglomerate and oolitic limestone.

Probable source areas for surficial glacial sediments in the Monture Creek drainage are shown as underlain by Belt Series sediments ranging from the Spokane Formation to the McNamara Formation, including large areas of the dominantly carbonate Helena Formation.

Between Monture Hill and the mountain front to the north, mapping shows several small patches of exposed valley-fill sediments ("lake beds") of mid to late Tertiary (Oligocene to Miocene) age. Elsewhere, Tertiary sediments are covered by glacial drift. Tertiary sediments are described as variable but dominantly fine-grained in character, locally calcareous and locally fossiliferous. In the Upper Blackfoot (Lincoln) area, similar sediments are described as pyritic. [See Indian Meadows entries.]

Lahurity Lake Southwest

See Lahurity Lake entries.

Lake Bowdoin (3 sites)

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index

Author: Bergantino, R.N.

Title: Altitude of the top of the Claggett Shale, Glasgow 1 degree
X 2 degree quadrangle.

Series: MBMG Open-file report 182

Date: 1987

Regional map compilation at 1:250,000 scale shows the natural catchment of Lake Bowdoin to be underlain by the Claggett Shale of Late Cretaceous age. Some contributing areas to the south may be underlain by the Late Cretaceous Judith River Formation, which overlies the Claggett Shale. Lake Bowdoin is shown to overlie the Bowdoin(?) structural dome southwest of it's apex.

This map has no accompanying text or hydrologic information. Surficial deposits are not shown.

Bibliographic source: U.S. Geological Survey request

Author: Lambing, J.H., W.E. Jones and J.W. Sutphin

Title: Reconnaissance investigation of water quality, bottom sediment and biota associated with irrigation drainage in the Bowdoin National Wildlife Refuge and adjacent areas of the Milk River basin, northeastern Montana, 1986-87

Series: U.S. Geological Survey Water-Resources Investigations
Report 87-4243

Date: 1987

This initial reconnaissance investigation included ground-water data from two sites south and southeast of Bowdoin, surface water samples from the Dodson South Canal and from 3 sites within Bowdoin, along with Lakeside and Dry Lake Units. Sediment samples were collected from 4 sites in Bowdoin, including one near the DHES "Lake Bowdoin North Shore" site, and from Dry Lake and Lakeside Units.

This publication includes a geologic map of the Lake Bowdoin area which shows a band of alluvium, linking the Beaver Creek alluvium with the Milk River alluvium, passing just south of Lake Bowdoin. There is no apparent reference to the characteristics of this

alluvium in text of tables.

The publication also includes an excellent schematic of water supply and routing options within the Lake Bowdoin Refuge.

Lake Mason.

Bibliographic source: Geoindex lat-long search.

Author: Zimmerman, E.A.

Title: Preliminary report on the geology and ground water resources of parts of Musselshell and Golden Valley counties, Montana.

Series: MBMG Information Circular no. 15

Date: 1956

Another early and minimal MBMG ground water effort. Map shows Lake Mason entirely underlain by "alluvium", which includes lacustrine deposits. Text describes "alluvium" of the Lake Mason basin as up to 40 feet thick but high in silt content, with small well yields.

The "alluvium" (or lacustrine silts) of the Lake Mason basin are mapped as overlying the Lance formation throughout. The Lance (uppermost Cretaceous) is composed of repeated sequences of sandstone, shale, clay and coal. The sandstone intervals are described as dependable but relatively low-yield aquifer(s). Inferred structure (not shown on map) appears to be anticlinal, so ground water discharge to the basin may be important.

Extensive areas of terrace gravels underlie higher portions of the basin, especially in the north. Extensive areas of Bearpaw Shale around basin margins, some Judith River Formation exposed. [Some proper structural mapping would be useful.]

Ground water from the Lance formation is described as relatively mineralized compared to Eagle and Kootenai aquifers. Generally, Lance Formation groundwater (6 samples) is relatively sodic and sulfate rich.

Bibliographic source: Geoindex lat-long search

Author: Reeves, Frank

Title: Geology of the Cat Creek and Devils Basin oil fields and adjacent areas in Montana

Series: USGS Bulletin 786-B

Date: 1927

This is a detailed (for it's time) report on the structure and stratigraphy of this area but includes no hydrology or hydrogeology. Lake Mason is at the southwestward extremity of the map area (map scale of 1:125,000), shown within an extensive area of undifferentiated surficial deposits. Upgradient areas of South Willow Creek shown with extensive areas of terrace gravels elevated above drainages. Lance Formation (transitionally overlying Bearpaw Shale) the principal bedrock outcrop shown in the basin.

Structural contours on the Third Cat Creek Sand of the Kootenai Formation show Lake Mason near the axis of syncline plunging slightly southward(??)

Lake Thibadeau Northeast

Bibliographic source: None, default reference

Author: Ross, Andrews and Witkind

Title: Geologic map of Montana

Series: None(?)

Date: 1955

Regional compilation at 1:500,000 scale shows the entire contributing basin underlain by the Bearpaw Shale of Late Cretaceous age. This map provides no useful information regarding surficial deposits. The site is within the limits of Pleistocene glaciation and is presumably underlain by till (presumably calcareous) of unknown thickness.

Neither automated searching of the Geoindex database nor manual searching of the MBMG publications index revealed any more useful geologic mapping of this area.

Lakeside.

See Lake Bowdoin entries.

Lamesteer

Bibliographic source: Geoindex lat-long search

Author: Ellis, M.S.

Title: Geologic map of the Powder River basin and surrounding area, Wyoming, Montana, South Dakota, North Dakota and Nebraska

Series: Miscellaneous Field Studies Map MF-2095

Date: 1989

Regional mapping at 1:500,000 scale limits the usefulness of this map. Refuge site is shown underlain by the Tongue River Member of the Fort Union Formation.

Bibliographic source: Geoindex lat-long search

Author: Vuke-Foster, S.M., R.B. Colton, M.C. Stickney, E.M. Wilde, J.E. Robocker and K.C. Christensen

Title: Geology of the Baker and Wibaux 30 X 60-Minute quadrangles, eastern Montana and adjacent North Dakota

Series: Montana Bureau of Mines and Geology Geologic Map 41

Date: 1986

Geologic mapping at 1:100,000 scale shows the reservoir and most of upper Lame Steer Creek underlain by the "third member" (from the bottom - Tongue River equivalent?) of the Fort Union Formation, with sandstone, coal and sandstone/siltstone/mudstone lithofacies described. There is no map indication of which of these lithofacies underlies the refuge site. Headwater areas east of the Refuge are underlain by the "fourth member" of the Fort Union, dominantly sandstone with thinner interbeds of nonexpansive clay.

Bibliographic source: Montana Bureau of Mines and Geology Publications Catalog

Author: Taylor, O.J.

Title: Ground-water resources along the Cedar Creek anticline in Eastern Montana

Series: Montana Bureau of Mines and Geology Memoir 40

Date: 1965

Geologic mapping at 1:175,000 scale shows the Lame Steer drainage as undifferentiated Fort Union Formation. Structural contouring shows the basal Fox Hills sandstone at an elevation of about 1930 feet in the vicinity of the Refuge, dipping northeastward down the eastern limb of the structure. Potentiometric mapping provides little information on the east side of the anticline; there is no indication of flowing wells nearby.

The text speaks almost entirely to aquifer characteristics and drawdown modeling in the Hell Creek/Fox Hills sandstone and does not discuss Fort Union or surficial aquifers. Water chemistry data for the Hell Creek/Fox Hills aquifer is included.

Lavina DOT Wetland Mitigation Site

Bibliographic source: Geindex lat-long search

Author: Ellis, A.J. and O.E. Meinzer

Title: Ground water in Musselshell and Golden Valley Counties, Montana

Series: USGS Water-Supply Paper 518

Date: 1924

Regional mapping at 1:250,000 scale shows the site underlain by the Judith River Formation, with upland areas to the north exposing Bearpaw Shale and Lance Formation. There is no information regarding the Musselshell alluvium in the vicinity.

LeBeau Creek South.

Bibliographic source: Geindex latlong search

Author: Harrison, J.E., E.R. Cressman and J.W. Whipple

Title: Preliminary geologic map of part of the Kalispell 1 X 2 Degree Quadrangle, Montana.

Series: U.S. Geological Survey Open-File Report 83-502

Regional mapping at 1:250,000 scale shows the LeBeau area underlain by middle Belt (Proterozoic Y) formations, with the Spokane and Empire Formations (dominantly clastic lithologies) at lower elevations and large areas of Helena Formation (dominantly calcareous and dolomitic lithologies) underlying topographic highs. Numerous northwest trending normal faults (structural elements of the "Rocky Mountain Trench") cross the general area.

Surficial deposits are only broadly differentiated at this scale.

Lee Metcalf National Wildlife Refuge

Bibliographic source: Geoindex lat-long search

Author: McMurtrey, R.G., R.L. Konizeski, M.V. Johnson and J.H. Bartells

Title: Geology and Water Resources of the Bitterroot Valley, Southwestern Montana

Series: U.S. Geological Survey Water-Supply Paper 1889

Date: 1972

Regional geologic mapping at 1:125,000 shows the refuge underlain by modern Quaternary alluvium of the Bitterroot River. "Low terrace alluvium", including probable fan material of the Burnt Fork and Ambrose Creek, is shown just to the east. Tertiary outcrops are shown three miles or more to the east. Potentiometric mapping at the same scale interprets a potentiometric high beneath the Burnt Fork. Water table depth at the time of mapping shown to be 5 feet at a well adjacent to sample site. Tabulated chemical analyses show dilute (<300 mg/l TDS) calcium bicarbonate ground water types beneath flood plain and terrace surfaces. Transmissivities are reported to be high, with well yields reported greater than 250 gallons per minute.

Long Lake WPA

Bibliographic source: Geoindex lat-long search

Author: Colton, R.B., R.W. Lemke and R.M. Lindvall

Title: Glacial map of Montana east of the Rocky Mountains

Series: U.S. Geological Survey Miscellaneous Geologic
Investigations Map I-327

Date: 1961

Regional mapping of surficial glacial features at 1:500,000 scale shows the Long Lake wetland near a mapped ice-marginal limit passing through Sunburst. Willshaw Flats appears to be shown as an upstream part of a major mapped drainage way connected southward to the Marias River valley.

Bibliographic source: None, default reference

Author: Ross, Andrews and Witkind

Title: Geologic map of Montana

Series: None

Date: 1955

Regional compilation at 1:500,000 scale shows the basin underlain by Colorado Shale of late Cretaceous age. Mapping at this scale provides no information regarding surficial deposits. Field observations indicate the area is underlain by glacial and lacustrine deposits of unknown thickness.

Mallard Pond

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index

Author: Bergantino, R.N.

Title: Prequaternary geology of the Wolf Point 1 degree by 2
degree quadrangle.

Series: MBMG Open-file report 171

Date: 1986

Regional compilation at 1:250,000 scale shows the glacial deposits of the wetland site to be underlain by undifferentiated Fort Union Formation of early Tertiary (Paleocene) age.

Bibliographic source: Montana Bureau of Mines and Geology

Publications Index

Author: Bergantino, R.N.

Title: Quaternary geology of the Wolf Point 1 degree X 2 degree quadrangle.

Series: MBMG Open-file report 172

Date:

Compilation at 1:250,000 scale shows Mallard Pond near the mapped contact between Clear Lake aquifer outwash deposits and a body of till to the west of Long Lake.

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index

Author: Donovan, J.J.

Title: Ground-water geology and high-yield aquifers of northeastern Montana

Series: MBMG Open-file report 209

Date: 1988

See Brush Lake entry for description of the study. Aquifer extent map at 1:100,000 scale shows Mallard Pond within the lateral boundaries of both the Clear Lake Outwash aquifer and the preglacial Missouri terrace gravels. Mallard Pond is listed but not classified according to groundwater outflow.

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index.

Author: Reiten, J.C.

Title: Water Quality of selected lakes in eastern Sheridan County, Montana.

Series: MBMG Open-file report 244

Date: 1991(?)

Mallard Pond is included as one of this study's sample sites. 1990 sampling indicates a substantial salinity gradient between sampling

points in this small lake (nearly 100% difference in specific conductance). No historical (pre-1990) water quality data are given.

Mary's Frog Pond

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index

Author: Sahinen, U.M.

Title: Mines and mineral deposits of Missoula and Ravalli
Counties, Montana

Series: Montana Bureau of Mines and Geology Bulletin 8.

Date: 1957

Generalized geologic map at a large scale appears to show Mary's Frog Pond underlain by undifferentiated Ravalli Group formations of Proterozoic Y (Belt) age, just across the contact from the granitic rocks of the Cretaceous-aged Idaho batholith. [This is an ambiguous map scale but was corroborated by a larger-scale map of the area, reviewed quickly once and not found since.]

Bibliographic source: None - DHES collection

Author: Rabe, F.W., R.L. Bursik and E.B. Cantor

Title: Classification and monitoring of wetlands in established
and proposed natural areas.

Series: Project report on USDA Forest Service Intermountain
Research Station Proposal #89009.

Date: 198?

This document contains a partial chemical analysis dating from June(?) or July(?) of 1987, along with biological inventory data. The site description refers to the basin as a "deep glacial scour" but provides no actual depth measurement.

Medicine Lake

Bibliographic source: Geoindex lat-long search

Author: Witkind, I.J.

Title: Quaternary geology of the Smoke Creek - Medicine Lake - Grenora area, Montana and North Dakota

Series: USGS Bulletin 1073

Date: 1959

Geologic mapping at 1:62,500 shows the area to be underlain by outwash deposits of late Wisconsin ("Mankato") age. The adjacent margins of the Dagmar Channel are shown underlain by extensive kame terrace deposits. Reconstruction of the late Wisconsin maximum ice extent shows the southern margin just south of Medicine Lake. The entire area is shown as an elongate southwestward oriented lobe, with Big Muddy Creek north of Medicine Lake largely ice-free.

Mikillop Creek Wetland

Bibliographic source: Geoindex lat-long search

Author: Johns, W.M.

Title: Geology and mineral deposits of Lincoln and Flathead counties, Montana

Series: Montana Bureau of Mines and Geology Bulletin 79

Date: 1970

Regional geologic mapping at 1:125,000(?) scale shows Mikillop Creek, including the sample site, underlain by undifferentiated glacial deposits. The contributing drainage basin is shown to be underlain the Wallace Formation on lower slopes and (probably) the Striped Peak Formation, both of Proterozoic Y (Belt) age. The Wallace Formation (Helena Formation equivalent) is dominantly calcareous and dolomitic; the Striped Peak Formation (Missoula Group) is composed mainly of argillitic and quartzitic lithologies.

Two mapped normal faults are shown intersecting very near or beneath the site. One is part of the dominant northwest trending series, parallel to the Thompson Lakes Fault to the north, and is shown extending up the (unnamed) south fork of Mikillop Creek and on to Horseshoe Lake, eventually merging with the Thompson Lakes Fault. The other trends east to northeast, crossing both forks of Mikillop Creek. Fault control of topography and of Mikillop Creek

wetland's distinct water chemistry are possibilities.

Mill-Willow.

Bibliographic source: Geoindex lat-long search.

Author: Konizeski, R.L., R.G. McMurtrey and A. Brietkrietz

Title: Geology and ground-water resources of the Deer Lodge Valley, Montana

Series: USGS Water-Supply Paper 1862

Date: 1968

Hydrogeologic mapping at scale of 1:62,500 shows the site underlain by undifferentiated Quaternary alluvium. Potentiometric interpretation shows adjacent reach of Silverbow Creek to be receiving ground-water discharge, but there were few data points to support this.

Gravimetric interpretation shows a gravity low centered just north of Opportunity, with relatively steeply increasing values eastward beneath the wetland area, showing thinning valley fill to the east from a maximum near valley axis.

Description of the characteristics of the alluvium includes the generalization that thickness averages about 20 feet on the Clark Fork floodplain, underlain by Pliocene sand and gravel. Beneath the "Willow Creek Flat", however, thickness is less than 10 feet and overlies volcanics. [Not clear exactly where the Willow Creek Flat is - possibly farther upstream on Willow Creek.]

Includes no water quality section.

Nine Pipe Reservoir (Outlet and Pothole)

Bibliographic source: Geoindex lat-long search

Author: Boettcher, A.J.

Title: Ground-water resources in the central part of the Flathead Indian Reservation, northwestern Montana.

Series: Montana Bureau of Mines and Geology Memoir 48

Date: 1982

Generalized surficial geologic mapping at 1:62500 scale shows only undifferentiated glacial deposits in the Nine Pipe area. Generalized potentiometric mapping shows a northward trough in regional surface beneath the reservoir. [This looks kind of strange and improbable, really.] Very generalized text, with no discussion of shallow flow systems in Nine Pipe area. Includes tabulated water chemistry from a number of wells in regional aquifer.

Bibliographic source: U.S. Geological Survey

Author: Slagle, S.E.

Title: Irrigation-canal leakage in the Flathead Indian Reservation, Northwestern Montana

Series: U.S. Geological Survey Water-Resources Investigations Report 92-4066

Date: 1992

This study used seepage-meter estimates of canal seepage at 5 sites on hydrogeologically distinct materials and a GIS of the canal system to generate canal seepage estimates for the entire Flathead Irrigation Projects system. One of these sites (the Charlo site) was on the Mission moraine, underlain by till of the same map unit as that underlying the Ninepipe sites several miles distant.

Observed differences in hydraulic conductivity correlated with differences in monitoring well response to canal head. In till facies of lower hydraulic conductivity, monitoring well response was subdued and only generally correlated with canal flows, while wells in more permeable till facies showed direct responses.

North Goose Lake

Bibliographic source: Montana Bureau of Mines and Geology Publications Index

Author: Bergantino, R.N.

Title: Prequaternary geology of the Wolf Point 1 degree by 2 degree quadrangle.

Series: MBMG Open-file report 171

Date: 1986

Regional compilation at 1:250,000 scale shows the area underlain by undifferentiated Fort Union Formation of early Tertiary (Paleocene) age.

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index

Author: Bergantino, R.N.

Title: Quaternary geology of the Wolf Point 1 degree X 2 degree quadrangle.

Series: MBMG Open-file report 172

Date: 1986

Regional compilation at 1:250,000 scale shows North Goose Lake straddling the contact between till to the north and the Clear Lake aquifer outwash gravel beneath the southern two-thirds of the lake basin. All of the southern lake basin is shown underlain by outwash.

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index

Author: Donovan, J.J.

Title: Ground-water geology and high-yield aquifers of northeastern Montana

Series: MBMG Open-file report 209

Date: 1988

Blue-line map of the extent of the Clear Lake aquifer shows North Goose Lake just outside of the 5-foot isopach of outwash sand and gravel, while the southeastern arm of the lake is within the 5 foot isopach. [Inference is that the broader area of outwash gravel

mapped by Bergantino, see above, is thinner than 5 feet.]

Both North Goose and the less saline Goose Lake are listed as restricted-outflow type lakes by Donovan.

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index.

Author: Reiten, J.C.

Title: Water Quality of selected lakes in eastern Sheridan County,
Montana.

Series: MBMG Open-file report 244

Date: 1991(?)

This compilation of northeastern Montana lake water quality includes one quantitative analysis from the northern basin of Goose Lake (North Goose Lake by DHES site usage) dating from 1990. There are also 6 field specific conductance measurements from various points in the lake taken in 1990, and 7 from similar sites taken in 1984, showing an approximate doubling of specific conductance during that period.

North Widgeon Slough WPA

See Comertown Preserve entries.

Odell - Skull Creek Proposed RNA

Bibliographic source: Geoindex lat-long search

Author: Berger, B.R., L.W. Snee and W. Hanna

Title: Mineral resource potential of the West Pioneer Wilderness
Study Area, Beaverhead County, Montana

Series: U.S. Geological Survey Miscellaneous Field Studies Map MF-

1585-A

Date: 1983

Geologic mapping at 1:50,000 scale shows the site underlain by glacial till, described as generally bouldery in character, covering bedrock units throughout the Odell Lake-Lacy Creek-Skull Creek Meadows area. Bedrock outcrops underlying the contributing basin are shown as Missoula Group formations (undifferentiated) of Proterozoic Y (Belt) age. Farther west large areas of various Cretaceous and Tertiary aged igneous rocks, mostly with granitic or granodioritic compositions, are shown. There are a few small scattered areas of Helena Formation (dominantly carbonate lithologies) of Proterozoic Y (Belt) age.

Mineral resource potential was evaluated for this study through stream sediment sampling for molybdenum, copper, lead, zinc and silver. The wetland site is just outside of a broad northwest-trending zone of identified potential for silver and gold mineralization containing several areas of identified molybdenum potential.

No direct structural information and no hydrologic information are provided.

Oilmont Wetland

Bibliographic source: Referenced L.K. Tuck (see Furnell references)

Author: Collier, A.J.

Title: The Kevin-Sunburst oil field and other possibilities of oil and gas in the Sweetgrass Arch, Montana

Series: U.S. Geological Survey Bulletin 812-B

Date: 1929

This document describes the structure and economic geology of the Kevin-Sunburst area as it was understood at the time. Structural contouring of the Madison Group shows the wetland site to be near the apex of the Kevin-Sunburst Dome. The publication does not include a geologic map per se but indicates the site is underlain by the Colorado Shale of Late Cretaceous age, possibly the Blackleaf Member.

Bibliographic source: Geoindex lat-long search

Author: Colton, R.B., R.W. Lemke and R.M. Lindvall

Title: Glacial map of Montana east of the Rocky Mountains

Series: U.S. Geological Survey Miscellaneous Geologic
Investigations Map I-327

Date: 1961

Regional mapping of surficial glacial features at 1:500,000 scale shows the wetland site just within a lobe of a mapped glacial advance (apparently correlative with the advance responsible for the Sweet Grass Hills end moraine). The glacial deposits in the area are mapped mainly as "ground moraine", although there is a thin band of end moraine shown associated with the ice advance limit. Concentrations of drumlinoid features and crevasse-fill deposits are shown within this advance lobe. Beyond the mapped maximum position of this lobe, the surface is mapped as (presumably older) "ground moraine".

Bibliographic source: None, default reference

Author: Ross, C.P., D.A. Andrews and I.J. Witkind

Title: Geologic map of Montana

Series: U.S. Geological Survey, no series

Date: 1955

The wetland is shown to be underlain by a broad area of undifferentiated Colorado Shale. Generalized regional mapping provides no information regarding surficial deposits.

Ontario Creek/Ontario Mine/Telegraph Creek

Bibliographic source: Geoindex lat-long search

Author: Ruppel, E.T.

Title: Geology of the Basin quadrangle, Jefferson, Lewis and Clark
and Powell Counties, Montana

Series: USGS Bulletin 1151

Date: 1963

Detailed geologic mapping (with emphasis on igneous units) at 1:48,000 scale shows the Ontario Creek and Telegraph Creek headwaters sites underlain by undifferentiated Elkhorn Mountain volcanics of late Cretaceous age. The wetland areas are near the contact with the Boulder batholith ("Butte Quartz Monzonite" unit) and are shown with a mappable (though probably thin) cover of undifferentiated glacial deposits.

The text includes extensive discussions of the mineralogy and petrography of different phases of igneous rocks mapped in the quadrangle. [Normative compositions of the Butte Quartz monzonite are $\text{Ca} > \text{Na} > \text{K}$.] Glacial deposits described include till and outwash; granitic cobbles and boulders in till are described as relatively deeply weathered, and the age of the glacial deposits is interpreted as early Wisconsin.

The Ontario Mine site is shown to be also underlain by the Butte Quartz Monzonite (Boulder Batholith) near the contact of a mass of aplite/alaskite underlying O'Keefe Mountain. The description of mines within the quadrangle does not appear to include the mine draining to the sample wetland, although the prospect is shown on the map.

Includes interesting mention of the 1898 injunction against mill in the Tenmile Creek drainage by the City of Helena to protect water supplies.

Pine Butte Fen

Bibliographic source: Geoindex lat-long search

Author: Mudge, M.R., R.L.Earhart, J.W. Whipple and J.E. Harrison

Title: Geologic and structure map of the Choteau 1 degree X 2 degree quadrangle, western Montana

Series: U.S. Geological Survey Miscellaneous Investigations Series Map I-1300

Date:

Regional compilation at 1:250,000 scale shows Pine Butte proper underlain by the Two Medicine and Horsethief Formations of Late Cretaceous age. Ridges to the west of the fen are underlain by the older Two Medicine Formation and underlying Virgelle Sandstone and

Telegraph Creek Formation, also of Late Cretaceous age. The Teton River canyon, presumed to be part of the source area for fluvial and glaciofluvial sediments underlying the fen, is underlain by numerous intercalated thrust fault slices of Mesozoic and Paleozoic rocks, including large areas of Mississippian-aged Madison Group limestone. The surficial sediments of the fen itself are shown to conceal the trace of the easternmost mapped thrust fault.

Bibliographic source: None - personal communications.

Author: Nimick, D.A., R.S. Rasmussen, W.W. Woessner and J. Schmidt

Title: Geologic and hydrologic investigations at Pine Butte and McDonald Swamps, Teton County, Montana.

Series: Unpublished report to The Nature Conservancy Montana Field Office.

Date: 1983

This report documents a reconnaissance-level investigation of the geologic, hydrologic and geometric controls on the formation and behavior of the Pine Butte and McDonald fens. The deposition of glacial and post-glacial sediments forming the aquifer supporting the fens is described, and hydrologic data including synoptic discharge measurements along the losing reach of the Teton River, potentiometric data from piezometers completed within and beneath the fen sediments, and discharge data for streams draining the fen are provided and discussed. (Streams draining the fen are described as perennial.) Very rough calculations of ground-water flux through the Pine Butte fen system are offered, and some limited qualitative interpretations of bedrock aquifer relationships are provided. (Bedrock is considered to be an unimportant contributor to the hydrologic system of the fen.)

The basic qualitative interpretation of the study is that ground-water discharge from the underlying unconsolidated aquifer system provides hydrologic support for the fen, and that seepage loss from the Teton River upgradient from the fen provides the largest component of recharge to the unconsolidated aquifer.

Sands WPA

Bibliographic source: Geoindex lat-long search

Author: Hearn, B.C. Jr.

Title: Geologic and tectonic maps of the Bearpaw Mountains area, north-central Montana.

Series: USGS Miscellaneous Investigations Series I-919

Date: 1976

Detailed regional geologic mapping at 1:125,000 scale shows the sample site and most of Halfway Lake underlain by the Judith River Formation of late Cretaceous age. The northernmost arm of the lake extends across a minor normal fault and into a small graben preserving late Cretaceous Bearpaw Shale and a small area of Tertiary volcanic rocks.

The contributing basin is underlain mainly by Judith River Formation, with secondary but substantial areas of Bearpaw shale and Tertiary-aged volcanic flows, and minor areas of Colorado Shale and Eagle Formation.

No direct information regarding hydrology is provided.

Schrammeck Lake

Bibliographic source: Montana Bureau of Mines and Geology
Publications Index

Author: Fox, R.D.

Title: Geology and ground-water resources of the Cascade-Ulm area,
Montana

Series: Montana Bureau of Mines and Geology Bulletin 52

Date: 1966

Geologic mapping at 1:62,500 scale shows Schrammeck Lake and most or all of its contributing basin underlain by the Bootlegger (upper) member of the Blackleaf Formation (of the Colorado Group) of early Cretaceous age. Within the map area, regional dips are to the west and the Bootlegger is unconformably overlain by the Marias River Formation of late Cretaceous age. The map shows no mapped structures in the Schrammeck Lake area other than bedding orientation.

The Bootlegger Member is described as "interbedded black shale, greenish bentonite, brownish sandstone and chert pebble conglomerate". Bentonitic outcrops are described as exhibiting salt efflorescences. Chert pebble conglomerates are believed to have been derived from erosion of the Permian-aged Phosphoria Formation.

No mappable surficial deposits are shown in the Schrammeck Lake basin. There is a large area of dune sand shown several miles to the north, marginal to the Missouri River floodplain.

The text includes a very interesting description of springs discharging from the Bootlegger member. These are described as numerous in the area, but of low yield and poor quality, typically with salt efflorescences. Geyser Creek just north of Schrammeck Lake is named for groundwater discharge features in bentonitic Bootlegger Formation, forming holes and depositional cones.

The few water quality analyses provided do not include any from the Bootlegger Member. There is one analysis from a well in the Flood Member (basal sandstone) of the Blackleaf. It has subequal concentrations of divalent and monovalent cations, nearly equal bicarbonate and sulfate concentrations, and TDS of 1078 mg/l.

Spidel WPA

Bibliographic source: Geoindex lat-long search

Author: Ellis, M.S.

Title: Geologic map of the Powder River basin and surrounding areas...

Series: USGS Miscellaneous Field Studies Map MF-2095

Date: 1989

Regional mapping at a scale of 1:500,000. See other entries under this title.

Bibliographic source: Geoindex lat-long search

Author: Ellis, A.J. and O.E. Meinzer

Title: Ground water in Musselshell and Golden Valley Counties, Montana

Series: USGS Water-supply paper 518

Date: 1924

Regional mapping at a scale of 1:250,000 includes the sample site at southern extremity of map coverage. Structural interpretation

shows the Spidel basin lying on the western limb of the Bull Mountains structural basin, immediately underlain by the Lance Formation, with Bearpaw Shale and Judith River Formation to the west and Fort Union Formation to the east. The basin itself is mapped as an extensive area underlain by lacustrine (or paludal??) deposits.

Page 7 includes an interesting discussion of the Lake Basin and Comanche Lake structural impoundments but does not discuss the Spidel basin. Page 40-41 includes water chemistry from a number of Lance Formation wells but none from the immediate township.

The report is organized with hydrogeologic descriptions by township. The inventory for T5N R23E includes one well completed in section 28, completed somewhere between 75 and 116 feet, and one dug well in section 30, both considered to be finished in the Lance, both yielding adequate domestic supply. No records of water levels are included.

Swamp Gulch

Bibliographic source: Geoindex latlong search

Author: Whipple, J.W., M.R. Mudge and R.L. Earhart

Title: Geologic map of the Rogers Pass area, Lewis and Clark County, Montana.

Series: U.S. Geological Survey Miscellaneous Investigations Series Map I-1642

Date: 1987

Detailed bedrock geologic mapping at 1:48,000 scale shows Swamp Gulch itself underlain by the dominantly clastic Spokane Formation and the transitional Empire Formation (Proterozoic Y), with none of the dominantly calcareous and dolomitic Helena Formation within the watershed. The outcrops at the mouth of the drainage are mapped as Proterozoic Z intrusives (diorite). A portion of the Mike Horse Stock (Paleocene/Eocene monzonite porphyry or quartz monzonite porphyry).

Upgradient contributing drainages (Pass Creek, Anaconda Creek, etc.) are underlain by the same lithologies, with the addition of small areas of Helena Formation at higher elevations along the divides.

Structurally within the Hoadley Thrust Plate, one of a series of stacked thrust plates shown on the map area. Dips shown are low

to moderate to the NE to NW.

The Quaternary deposits of the sample wetland are shown simply as alluvium.

This is the best bedrock map of the area reviewed.

Bibliographic source: Geoindex lat-long search

Author: Mudge, M.R. and R.L. Earhart

Title: Bedrock geologic map of part of the Northern Disturbed Belt, Lewis and Clark, Teton, Pondera, Glacier, Flathead, Cascade and Powell Counties, Montana

Series: U.S. Geological Survey Miscellaneous Investigations Series Map I-1375

Date: 1983

Regional geologic mapping at 1:125,000 scale shows the Swamp Gulch area underlain predominantly by Proterozoic Y Spokane Formation, with Proterozoic Y Empire Formation probably at upper elevations in the headwaters. The Proterozoic Z diorite also is exposed in the Pass Creek and Swamp Gulch(?) drainages, and Tertiary hornblende monzonite and monzonite porphyry are intruded into the proterozoic rocks of the region.

The Empire and Spokane formations are described as predominantly clastic lithologies, but including calcareous cement and carbonate interbeds, described as limestone in the Spokane and both dolomite and limestone in the Empire Formation.

Bibliographic source: None - agency file search

Author: Dollhopf, D.J., J.D. Goering, R.B. Rennick, R.B. Morton, W.K. Gauger, J.B. Guckert, P.M. Jones, K.C. Cooksey, K.E. Bucklin, R. Weed, and M.M. Lehman

Title: Hydrochemical, vegetational and microbiological effects of a natural and a constructed wetland on the control of acid mine drainage.

Series: Montana Department of State Lands Abandoned Mines Reclamation Bureau Final Report on contract 2-6000-230, performed by the Montana State University Reclamation Research Unit.

Date: 1988

This document provides detailed analysis of the distribution and

geochemical occurrence and control of metals derived from the abandoned Carbonate Mine in the Swamp Gulch wetland. The study included measurements of hydraulic conductivity in the wetland sediments, potentiometric mapping of the shallow ground-water flow system, discharge data from Swamp Gulch, metals uptake data for wetland vegetation and other data. The study compared metals immobilization by the natural Swamp Gulch wetland with that in the constructed wetland at Sand Coulee, an acid mine drainage site in Cascade County. The Swamp Gulch site was found to be much more effective, apparently because it supports healthier populations of sulfate-reducing bacteria effective in precipitating metal sulfides.

Swan River Proposed RNA

Bibliographic source: Geoindex lat-long search

Author: Mudge, M.R., R.L. Earhart, J.W. Whipple and J.E. Harrison

Title: Geologic and structure map of the Choteau 1 degree X 2 degree quadrangle, western Montana.

Series: U.S. Geological Survey Miscellaneous Investigation Series Map I-1300.

Date: 1982

Regional map compilation at 1:250,000 scale shows the upland slopes above the site to be underlain entirely by the Helena Formation (Belt Supergroup) of Proterozoic Y age. The Helena Formation consists predominantly of carbonate lithologies (limestone and dolomite) and generally calcareous clastic sediments.

Bibliographic source: Geoindex lat-long search

Author: Witkind, I.J. and M. Weber

Title: Reconnaissance geologic map of the Big Fork-Avon environmental study area, Flathead, Lake, Lewis and Clark, Missoula and Powell counties, Montana

Series: USGS Miscellaneous Investigations Map I-1380

Date:

Regional geologic mapping at 1:125,000 scale emphasizing surficial

geology. Sample site is shown to be near the contact of modern alluvium and "valley facies" of late Pleistocene till. The till facies is described as loose and having a sandy matrix. The knob elevated above the valley floor is shown as a kame deposit on this map, rather than a drumlin as it is described elsewhere. There is no subsurface or hydrologic information included.

Telegraph Creek.

See entries under Ontario Creek.

Tew WPA

Bibliographic source: Geoindex lat-long search

Author: Ellis, M.S.

Title: Geologic map of the Powder River basin...

Series: USGS Miscellaneous Field Studies Map MF-2095

Date: 1989

Regional compilation at 1:500,000 scale. See other entries.

Bibliographic source: Geoindex lat-long search

Author: Woolsey, L.H., R.W. Richards and C.T. Lupton

Title: The Bull Mountain coal field, Musselshell and Yellowstone Counties, Montana

Series: USGS Bulletin 647

Date: 1917

Regional mapping at 1:125,000 scale shows the Tew WPA apparently underlain by the Lebo Shale member of the Fort Union Formation, with mappable accumulations of "alluvium" (probably lacustrine or paludal sediments) shown within two or three nearly-closed basins. The text provides no description of these surficial sediments nor any discussion of the hydrologic characteristics of the map area.

Tooley (aka Toole) Lake

Bibliographic source: Geoindex lat-long search

Author: Coffin, D.L., A. Brietkrietz and R.G. McMurtrey

Title: Surficial geology and water resources of the Tobacco and Upper Stillwater River Valleys, Northwestern Montana

Series: Montana Bureau of Mines and Geology Bulletin 81

Date: 1971

Surficial geologic mapping at approximately 1:100,000 scale shows Tooley Lake underlain by glaciolacustrine sediments of Glacial Lake Kootenai(?). Nearby exposures of glaciolacustrine sediments are up to 300 feet in thickness. Glaciolacustrine sediments in the study area are described as predominantly silt and very fine sand with thin (less than 1 foot) clay interbeds. Spring discharges from these sediments are described, but well completions are reportedly rare and avoided by drillers due to heaving tendencies.

Upslope areas amounting to approximately half of the contributing drainage are underlain by drumlin - marked till, described in near-outcrop areas (as this is) as being boulder-rich [although the drumlins imply it is still predominantly fine - grained.]

Specific conductance measurements collected in June and October of 1968 were 670 and 800 microsiemens, respectively. No quantitative water chemistry from the lake or from wells in the immediate vicinity are provided.

Analog steady-state ground water flow model (!), with head apparently tied to Tooley Lake, produced steep potentiometric gradient between the lake and the Kootenai River.

Bibliographic source: Geoindex lat-long search

Author: Johns, W.M.

Title: Geology and mineral deposits of Lincoln and Flathead Counties, Montana

Series: Montana Bureau of Mines and Geology Bulletin 79

Date: 1970

Relatively detailed pre-Cenozoic geologic mapping shows slopes to the west underlain by undifferentiated Ravalli Group rocks of Proterozoic Y (Belt) age. Ravalli Group rocks are described as

predominantly argillites and quartzites, with important calcareous units only near the top of the section. Upper basins of Dodge Creek and Young Creek, which bracket the small drainage feeding Tooley Lake, drain areas of undifferentiated Piegan Group (carbonate rich and pyritic in the Siyeh Formation) the Siyeh Formation proper.

Bibliographic source: None - DHES collection

Author: Rabe, F.W., R.L. Bursik and E.B. Cantor

Title: Classification and monitoring of wetlands in established and proposed natural areas.

Series: Project report on USDA Forest Service Intermountain Research Station Proposal #89009.

Date: 198?

This document provides field chemical characteristics (pH and conductivity) for Tooley Lake (known as Toole Lake in this report) in July 1988. The report also provides an inventory of the biological characteristics of the lake.

Townsend Valley Wetland

Bibliographic source: Geoindex lat-long search

Author: Lorenz, H.W. and R.G. McMurtrey

Title: Geology and occurrence of ground water in the Townsend Valley, Montana.

Series: U.S. Geological Survey Water-Supply Paper 1360-C

Date: 1956

Regional geologic mapping at 1:96,000 scale shows the area underlain by undifferentiated quaternary alluvium. Generalized potentiometric mapping at 1:62,500 scale shows the site near or within an area identified as waterlogged at the time of the study. Tabulated water level records indicate wells in the site section fluctuated 6 -10 feet during the investigation, with maximum water levels on the order of 15 feet.

Tabulated water chemistry for the Quaternary alluvium in the

general vicinity indicates unremarkable calcium/bicarbonate-to-mixed water types, generally under 1000 microsiemens/cm in conductivity.

Bibliographic source: Geoindex latlong search

Author: Freeman, V.L., E.T. Ruppel and M.R. Klepper

Title: Geology of part of the Townsend Valley, Broadwater and Jefferson Counties, Montana

Series: U.S. Geological Survey Bulletin 1042-N

Date: 1958

Geologic mapping at 1:48,000 scale shows the site underlain by Quaternary alluvium, differentiated from fan deposits, pediment deposits and older Pleistocene terrace gravels. The emphasis of this document is on pre-Quaternary formations, and only a brief description of the characteristics of the Missouri alluvium is provided.

Turtle Lake

(See Alkali Lake entry.)

Bibliographic source: None - DHES collection

Author: Rabe, F.W., R.L. Bursik and E.B. Cantor

Title: Classification and monitoring of wetlands in established and proposed natural areas.

Series: Project report on USDA Forest Service Intermountain Research Station Proposal #89009.

Date: 1987

This document provides a partial (and suspect?) chemical analysis from June of 1987 along with biological inventory data from Turtle Lake.

Upper Red Rock Lake.

Bibliographic source: Geoindex lat-long search

Author: Sonderegger, J.L., J.D. Schofield, R.D. Berg and M.L. Mannick

Title: The Upper Centennial Valley, Beaverhead and Madison Counties, Montana

Series: MBMG Memoir 50

Date: 1982

This study was instigated as an evaluation of the geothermal potential of the Centennial Valley and adjacent areas of the Upper Madison valley. The structural geology of the Centennial Valley is described in detail, and the stratigraphy and paleogeography of Cenozoic volcanic and volcanoclastic rocks also receives emphasis. Outcrops on the southern end of the Gravelly Range are dominantly the Huckleberry Ridge Tuff and other Quaternary volcanics mantling Paleozoic rocks. Outcrops are separated from the Lake by several miles of dune sand and Quaternary alluvium. Outcrops to the south across the Centennial fault are not mapped here but are described as including formations ranging in age from lower Cretaceous to Precambrian.

Ground-water chemistry from surficial aquifers on the north side of the valley (alluvium and aeolian sand) supports some mixing of deep-circulating geothermal water. Thermal imaging of the northern margin of Upper Red Rock Lake also supports some leakage of warm Madison Group ground water into the lake and nearby aquifers. Structural interpretation shows an inferred fault trace passing between Upper Red Rock and Swan Lakes, which is interpreted as the flow path for deeply circulating ground water discharge.

Geothermometry is interpreted as indicating only moderate reservoir temperatures of 45 degrees C or so (chalcedony thermometer).

Appendices include well summary and numerous water quality analyses which should be copied.

Bibliographic source: Geoindex lat-long search

Author: Witkind, I.J.

Title: Geologic map of the Centennial Mountains Wilderness Study area and contiguous areas, Idaho and Montana.

Series: USGS Miscellaneous Field Studies Map MF-1342-A

Date: 1982

Very good 1:50,000 scale map of the geology of the Centennials, but includes little mapping of the surficial deposits in the valley. Only the fan deposits along the mountain front are shown. Centennial scarp is mapped showing formations ranging from undivided Precambrian basement rocks up to Jurassic undivided near the divide.

Upper Stillwater River Wetland

Bibliographic source: Geindex lat-long search

Author: Elliot, J.E.

Title: Geologic map of the southwest part of the Cooke City Quadrangle, Montana and Wyoming.

Series: U.S. Geological Survey Miscellaneous Investigations Series Map I-1084.

Date: 1979

Detailed bedrock geologic mapping at 1:24000 shows the Upper Stillwater wetland underlain by Holocene-aged alluvium, which overlies an extensive area of undifferentiated Pleistocene-aged glacial deposits. No descriptions of the characteristics or thickness of the surficial geologic units is provided.

Glacial sediments upgradient from the sampling site cover sedimentary rocks of Cambrian age (including the calcareous Meagher and Pilgrim Limestones) and silicic to intermediate volcanic rocks (rhyodacite and latite) of early Tertiary (Eocene) age. Daisy Creek, an eastern tributary to the upper Stillwater River receiving acid mine drainage from the historic McLaren Mine, incises the glacial cover and exposes the Cambrian formations along it's upper channel.

The western margin of the wetland (as indicated by the extent of Holocene alluvium) and the upper Stillwater River above the sampling site are shown closely following a normal fault (downdropped to the east) which may exert some structural control on the drainage.

Bibliographic source: Geoindex lat-long search

Author: Lovering, T.S.

Title: The New World or Cooke City mining district, Park County, Montana

Series: USGS Bulletin 811-A

Date: 1929

This document emphasizes the petrology, mineralogy and economic geology of the New World District and adjacent areas. Geologic mapping at 1:31,360 scale is anachronistic, updated by Elliott (1979).

There is a very interesting description of native copper deposits found within organic-rich intervals of the upper Fisher Creek (?) alluvium near the lower Glengarry adit, across the Stillwater-Fisher Creek divide from the Upper Stillwater wetland. Lovering hypothesized bacterial reduction of oxidation products from exposed chalcopyrite nearby as the source. Lovering implies that this is a natural process not linked to mine drainage. Bacterial reduction was supported by an inoculation experiment resulting in the removal of copper from various copper sulfate solutions.

Lovering also describes extensive areas of limonitic cementation of post-Pleistocene(?) sediments on Red Mountain.

Wagner Basin RNA

Bibliographic source: Geoindex lat-long search

Author: Mudge, M.R.

Title: Bedrock geologic map of the Sawtooth Ridge quadrangle, Teton and Lewis and Clark counties, Montana.

Series: USGS Geologic Quadrangle Map GQ-381

Date: 1965

Wagner Basin is barely on the Sawtooth Ridge quad, and although it includes the Wagner Basin sampling site, it isn't completely clear whether the spring discharge point is within the area covered or not.

Wagner Basin is shown underlain by depositional sequence of

Kootenai, Morrison, Swift, Rierdon, Sawtooth, and Mississippian Castle Reef Dolomite(?). Dips are steeply westward. Possible aquifers include the Kootenai, Swift and Castle Reef Dolomite.

Bibliographic source: Geoindex lat-long search

Author: Mudge, M.R.

Title: Surficial geologic map of the Sawtooth Ridge quadrangle, Teton and Lewis and Clark counties, Montana

Series: USGS Geologic Quadrangle Map GQ-610

Date: 1967

Wagner Basin site is at the northern extremity of coverage by this sheet. Surficial deposits at the site are mapped as alluvium. Outwash deposits are mapped along western margin of the basin to the west of the wetland. Terrace gravels, reportedly about 20 feet thick, presumably Sun River gravels, are shown at the lower edge of the basin along Diversion Lake.

Bibliographic source: Geoindex lat-long search

Author: Mudge, M.R. and R.L. Earhart

Title: Bedrock geologic map of part of the northern Disturbed Belt, Lewis and Clark, Teton, Pondera, Glacier, Flathead Cascade and Powell Counties, Montana

Series: U.S. Geological Survey Miscellaneous Investigation Series Map I-1375

Date: 1983

Geologic mapping at scale of 1:125,000 shows the Wagner Basin area underlain by intercalated thrust fault slices of Madison Group, undifferentiated Mount Pablo Formation (Lower Cretaceous), Morrison Formation and Ellis Group (Upper Jurassic). Dips are westward at 30 to 65 degrees.

The Mount Pablo Formation consists of up to 90 meters of nonmarine sediments, including up to 10 meters of lacustrine limestone near the top of the section. The Ellis Group described as predominantly clastic marine sediments of varying lithology, including phosphatic beds. The description of Madison Group Formations includes dolomite increasing westward, but no mention of gypsum or other evaporites.

Warhorse Lake

Bibliographic source: Geoindex lat-long search.

Author: Perry, E.S.

Title: Artesian wells as a source of water for the Winnett Irrigation Project, Montana

Series: MBMG Miscellaneous Contributions no. 1

Date: 1932

This document has no plates, providing only a 1:126,720 (.5 inch/mile) line map with structure contours. The entire Warhorse basin is shown as Colorado Shale, with younger Cretaceous units outcropping far upgradient toward the Judith Mountains and downgradient on lower Boxelder Creek.

Perry discounts the importance of ground-water discharge to Fords Creek on structural grounds (dips are away from the drainage). Warhorse Lake itself occupies northwestward plunging synformal structure (Reeves, 1927) with no formations above the Colorado exposed, suggesting little likelihood of ground-water contribution.

Perry notes ubiquitous presence of gypsum (selenite) in the Colorado shale outcrops of the area.

Perry also noted that Warhorse was dry during the summer of 1941.

Bibliographic source: Geoindex lat-long search

Author: Reeves, Frank

Title: Geology of the Cat Creek and Devils Basin oil fields and adjacent areas in Montana

Series: USGS Bulletin 786-B

Date: 1927

See entry under Lake Mason also.

Warhorse Lake is near the northwestern corner of the map area. All of the catchment shown is underlain by Colorado Shale. Middle and upper Ford's Creek (which is/was diverted into Warhorse) is not mapped. Warhorse occupies a position near the axis of a minor syncline between the Kootenai Dome to the north and the McDonald

Creek anticline to the south.

Includes measured section of Colorado Shale from the nearby Kootenai Dome, with discussion of the lithologic characteristics of the notable marker beds within it, but no map indication of Lake Mason's position within the Colorado section.

Warm Springs Ponds (all sites)

Bibliographic source: Montana State Library subject file search

Author: Montana Department of Health and Environmental Sciences
(prepared by CH2M Hill, Inc. and Chen-Northern, Inc.)

Title: Final Silver Bow Creek CERCLA Phase II Remedial
Investigation Data Summary, Warm Springs Operable Unit

Series: Silver Bow Creek Investigation

Date: 1989

This document contains summaries and discussion of all data collected as part of the Remedial Investigation, along with the data themselves in two volumes of appendices. Analyses from numerous water and sediment sampling sites within the three Warm Springs Ponds are included in the data set. Contaminant concentrations in ground water are contoured for the ponds and surrounding areas. Algal counts and taxonomic distributions are included.

Bibliographic source: Montana State Library subject file search

Author: Montana Department of Health and Environmental Sciences
(prepared MDHES and CH2M Hill)

Title: Draft Feasibility Study for the Warm Springs Ponds
Operable Unit

Series: Silver Bow Creek Investigations

Date: 1989

This document contains analyses of alternative remediation plans considered for the Warm Springs Ponds and Mill-Willow Bypass areas. The report includes summaries of the geologic and hydrogeologic setting, pond history and contaminant transport pathways and mechanisms, sediment data, and risk assessment for human exposure. Aquatic life of the ponds is not an emphasis of this document.

Section 2 contains summary data (elevations, volumes, capacities of inlet and outlet structures, etc.) for the ponds, as well as statistical summaries of water and sediment chemistry data.

Bibliographic source: Geoindex lat-long search.

Author: Konizeski, R.L., R.G. McMurtry and A. Brietkrietz.

Title: Geology and Ground-Water Resources of the Deer Lodge Valley, Montana

Series: U.S. Geological Survey Water-Supply Paper 1862.

Date: 1968

[See Mill-Willow for primary abstract.]

Geologic mapping at 1:62500 scale shows Tertiary sediments immediately to the west of the facility, which is underlain by alluvium of Silver Bow and Warm Springs(?) Creeks. The Ducks Unlimited site is underlain by alluvium of Warm Springs Creek. Reported water table depths range from 9 feet beneath the ponds, to 1 foot adjacent to ponds, to 7 feet in the vicinity of the DU pond.

Gravity interpretation shows a bedrock high along the valley margin to the south of the facility; it may continue northward beneath the ponds. Depth of total valley fill beneath the DU site is probably hundreds of feet, depth of Warm Springs Creek alluvial fan deposit probably thinning toward reported axial maximum of 20 feet, with Tertiary (channel facies??) material underlying fan deposits.

White Lake

See Brush Lake entries.

Yellowstone River at Miles City

Bibliographic source: Geoindex lat-long search

Author: Ellis, M.S.

Title: Geologic map of the Powder River basin and surrounding area..

Series: USGS Miscellaneous Field Studies Map MF-2095

Date: 1989

Regional compilation at a scale of 1:500,000. See other entries.

Bibliographic source: Geoindex lat-long search

Author: Colton, R.B., S.J. Luft and G.P. Cormier

Title: Photogeologic and reconnaissance geologic map of the Miles City quadrangle, Montana

Series: USGS Miscellaneous Field Studies Map MF-1682

Date: 1984

Surficial geologic mapping at 1:24,000 scale shows the site to be an abandoned side channel of the Yellowstone, developed along the edge of the modern Yellowstone floodplain and just below the Holocene/Pleistocene(?) terrace underlying Miles City. The map provides only a generalized description of the alluvial material, citing literature describing it's thickness as up to 15 meters.

The adjacent bedrock outcrops on both sides of the Yellowstone are mapped as the Tullock Member of the Fort Union Formation, which is described as lithologically similar to the overlying Lebo Member, but having a higher proportion of sandstones.

This map provides no description of the hydraulic characteristics of the map units.

Bibliographic source: Geoindex lat-long search

Author: Lewis, B.D. and R.S. Roberts

Title: Geology and water-yielding characteristics of rocks of the northern Powder River Basin, southeastern Montana

Series: USGS Miscellaneous Investigations Series Map I-847-D

Date: 1978

Regional mapping at 1:250,000 scale ends at the Yellowstone River, showing geology on the southern side only. Lower outcrops along the river are shown as the Tullock Member of the Fort Union Formation, with extensive Lebo Member outcrops and a broad upland area of the Tongue River Member to the southeast.

Descriptions of the hydraulic characteristics of the Yellowstone alluvium are generalized only, with reference to possible yields up to several hundred gallons per minute.

Bibliographic source: Geoindex lat-long search

Author: Torrey, A.E. and F.A. Swenson

Title: Ground-water resources of the lower Yellowstone River valley between Miles City and Glendive, Montana

Series: USGS Circular 93

Date: 1951

This report was part of the series of investigations designed to evaluate the effects of new irrigation projects along the lower Yellowstone River. Areas near Miles City, however, are shown as already irrigated at the time under the Tongue-Yellowstone Irrigation Project.

The Miles City area is underlain by a structural basin, with groundwater recharge to the west (the Porcupine Dome) and to the east (the Cedar Creek anticline) supporting flowing wells completed in the Fort Union and Hell Creek aquifers underlying the alluvium in the vicinity of Miles City.

Drainage problems on the Tongue-Yellowstone project were considered minimal at the time, following several decades of irrigation. Water level records are reported for several observation wells within the section of the sampling site, with levels ranging from about 7.5 to about 16 feet below the surface at the time.

Water quality sampling identified characteristic high-Na water quality from all flowing wells in the study area. It may be possible to identify mixed contribution to wetland water chemistry.

There is also a discussion of the geomorphology of terraces along the lower Yellowstone, with six terrace elevations above the modern floodplain identified.

Appendix D

Source Documentation for Hydrogeomorphic Database of the DEQ Wetland Characterization Sites

Hydrogeomorphic database field documentation

Location (Fields dlat, dlong, mlat, mlong, slat and slong).

Sampling locations are based upon Randy Apfelbeck's mapped site locations indicated on 7.5 minute USGS topographic quadrangle maps. In some cases sampling sites were marked on the topographic maps in the field during sampling; in other cases the maps were not used in the field, and locations were reconstructed later from field notes. In most cases these map locations are believed to be accurate to a tolerance of ± 5 seconds latitude and longitude. At some sampling sites along low-angle, transient shorelines, accuracy may be less but probably is no worse than ± 10 seconds latitude and longitude.

The translation of mapped sampling points to the 6-field DBase locations was done manually using mylar overlays on the topographic quadrangles. The overlay translation is believed to be precise within ± 2 or 3 seconds of latitude and longitude.

The ArcInfo point coverage of sample site locations is generated from the manually translated dBase location fields and carries the same accuracy and precision.

Elevation (Field Site el).

Site elevations (in feet above MSL) are derived from mapped elevations of the sampled wetlands shown on 7.5 minute topographic quadrangles. Visual interpolations of elevations between contour intervals are made where appropriate. Accuracy of the interpolated map elevations are dependent on map accuracy and contour intervals. Elevations in the dBase field are not modified to account for differences between water levels at the time of sampling and those in the photobase for the topographic quadrangles.

Maximum drainage basin elevation (Field basn max).

Maximum drainage basin elevations (in feet above MSL) were determined manually from topographic mapping. For sample wetlands with smaller drainage basins, basin maximum elevations were derived from 7.5 minute topographic quadrangles with contour intervals of 40 feet or better. For some sites with large contributing basin areas, maximum basin elevations were determined from small-scale topographic maps with contour intervals as large as 200 feet. In the case of wetland and lake basins with known substantial water imports (such as Ninepipe Reservoir), the basin is taken to include the areas contributing to source of the imports, and the drainage basin maximum elevation reflects areas contributing imported water.

Surface water inlet and outlet (Fields surf in and surf out).

Surface water inlet and outlet codes reflect the appearance of these features on the most current 7.5 minute USGS topographic quadrangle maps. In a few cases (the Blackfoot WPA for instance) field observations of inlet or outlet features disagree with map symbology. In these cases field observations prevail.

Reservoirs are coded as having surface water outlets even where spillways are known to convey water only periodically. All inlet and outlet streams, including those shown as non-perennial on the topographic quadrangles, are considered.

Hydrologic manipulation (Fields impound and import).

The existence of impoundments (dams or dikes) and water imports are coded on the basis of features shown on the most current 7.5 minute topographic quadrangles, supplemented with information gathered in the field and from land management agencies. The shortcomings of using topographic map data are recognized; nevertheless map data probably identify most of the significant hydrologic modifications of these types.

There are a handful of known sites (and probably others) where abandoned or breached structures which are no longer functional controlled water inputs and storage at one time, (e.g., Jarina). Where known, these types of wetlands are coded as lacking these structural features.

Mean Annual Evaporation rate (Field Evap)

The value entered in the Evap field is the Penman method value (in inches per year) for the MAPS database cell within which the sample site is located. The use of Penman values is not intended to suggest that they necessarily represent the best estimates of evaporative and evapotranspirative water loss from the sampled wetlands. The values are intended as relative indices of the intensity of evaporative forcing. Penman potential evaporation and Thornwaite potential evapotranspiration values are both available statewide through the MAPS atlas; when compared to pan evaporation data for 12 longer-term climatic sites, Penman values appear to be a more sensitive index of measured (pan) rates and are therefore considered a more useful value against which to evaluate wetland characteristics.

Mean Annual Precipitation (Field Mean pre)

The values entered in the mean precipitation field are the mean of the range of values (in inches per year) for the MAPS database cell within which the sample site is located. These MAPS values were in turn derived from the 1978 Soil Conservation Service compilation of Montana precipitation for the 30-year period 1941-70 (Caprio et al, 1994). The MAPS site values were compared to the

individual NOAA station records considered most representative of the individual wetland sites in order to evaluate longer historical records and more recent local climatic trends.

The use of mean cell values to approximate site mean annual precipitation is arbitrary and introduces error to this field. In mountainous areas with steep precipitation gradients and large precipitation contour intervals in the 1978 compilation, this error may be fairly large. There is probably a tendency to overestimate precipitation values relative to the 1978 interpolation in these cases, since the wetland site locations are probably biased toward lower elevations within the elevation range of any given MAPS cell.

Wetland Area (Field Wet Area)

Wetland areas for the sampled wetlands are derived from ArcInfo coverages of the sites. For smaller sites which do not appear as hydrographic features in the 1:100,000 RF3 coverages, wetland areas were digitized from 7.5 minute topographic sheets. In all cases and particularly for smaller sites or those with transient extent, precision is low. Areas may not reflect free water extent at the time of sampling, and are not intended to represent jurisdictional wetland areas.

Drainage Basin Area (Field Basin Area)

Drainage basin areas for the sampled wetlands (in acres) are derived from Arcinfo coverages of contributing catchment areas. For sites with smaller contributing basins (those covering 1 or 2 7.5 minute topographic quadrangles), basin boundaries were digitized from manually drawn boundaries on the 7.5 minute quads. For sites with larger contributing basins, boundaries were estimated from the 1:100,000 RF3 hydrographic coverage of Montana. For sample wetlands known to receive a large fraction of their water from interbasin imports (e.g, Lake Bowdoin, Ninepipe Reservoir, Homestead Lake), basin areas for the streams contributing imported water are included.

Surficial and bedrock geologic units (fields Surf geo and Bed geo.)

Surficial and bedrock geologic fields are occupied by the U.S. Geological Survey alphanumeric codes for geologic units in Montana. Geologic units were determined from the best available geologic mapping of the wetland, cited in the accompanying Annotated Bibliography of Wetland Site Geology. Geologic units are those interpreted to be underlying the wetland itself; other geologic units may underlie the contributing drainage basin.

The coding system does not include paludal or modern lacustrine sediments, which are a ubiquitous feature of the sample sites. The provisional codes 110"LAC", 111"LAC" or 112"LAC" are adopted for sites where (nonglacial) lacustrine sedimentation is

known or inferred to dominate the surficial geology of the site. Recent chemical sediments are also outside of the coding system and are not recognized in these database fields. Where no information regarding surficial deposit is available, this field is left blank.

Geologic units are specified at the lowest hierarchical level supported by the available information, which varies between sites. Thus a more general code (400BELT) may be used if a more specific one (400WLLC) cannot be determined from the available information. Where the wetland is known to be underlain by more than one geologic unit, the field is coded for the hierarchically lowest common stratigraphic division. For example, a wetland known to be underlain by both the Two Medicine and Telegraph Creek Formations (of the Montana Group) would be coded 211MNTN (the Montana Group). Where the wetland is known to be underlain by geologic units of different eras, the field is coded for the geologic unit having the greater extent within the drainage basin of the wetland.

Calcite, aragonite, dolomite and gypsum saturation indices.

Aqueous solution composition and saturation indices were calculated using PCWATEQ, a DOS-driven version of the chemical equilibrium program WATEQF. Since dissolved analyses were conducted only for major components, no equilibrium calculations were performed for phases involving iron or other trace constituents. As applied, these solution equilibria are of interest mainly in identifying the theoretical saturation status of major carbonate and sulfate mineral phases. Analytical bicarbonate and carbonate concentrations were used in the WATEQPC input (Alkalinity Option 2); field dissolved oxygen measurements were used for calculating pE, and the Davies equation was used for all samples (including highly saline sites.)